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HF radio provides a low-cost, long-range communications alternative to satellite communication (SATCOM). In the polar environment, however, the frequent occurrence of dense sporadic E layers during summer in high-sunspot periods can prevent propagation in the HF band for the desired communications ranges. During solar storms, intense radiation may induce significant D-region absorption which further reduces the utility of HF radio. These phenomena cannot be defeated by the use of automatic link establishment (ALE) HF radio equipment because of the broadband nature of these effects. The use of VHF communication techniques, such as meteor scatter, provide a viable supplement to maintain connectivity when normal ALE HF radio is ineffective. This study combines the analysis of Scott Base Ionosonde data with computer predictions using A Stand-Alone Prediction Program (ASAPS) from the Australian Radio Prediction Service and IONCAP from the Institute for Telecommunications of the U.S. Department of Commerce to quantify the possibility of HF communications and suggest suitable radio system design parameters. Similarly, predictions of meteor burst (MF) link performance are provided for comparison with available measurements so that comparisons may be performed with actual link operations. Finally, an HF/VHF radio system design is envisioned to meet polar communications requirements and follow-on work to develop and verify design details is recommended.

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HIGH FREQUENCY (HF) AND METEOR BURST COMMUNCIATIONS IN A POLAR ENVIRONMENT

BACKGROUND

HF radio provides a low-cost, long-range communications alternative to SATCOM. In the polar environment, however, the frequent occurrence of dense sporadic E layers during summer in high-sunspot periods can prevent propagation in the HF band for the desired communication ranges. During solar storms, intense radiation may induce significant D-region absorption which further reduces the utility of HF radio. These phenomena cannot be defeated by the use of automatic link establishment (ALE) HF radio equipment because of the broadband nature of these effects. The use of VHF communication techniques, such as meteor scatter, provide a viable supplement to maintain connectivity when normal ALE HF radio is ineffective. This study combines the analysis of Scott Base Ionosonde data with computer predictions using A Stand-Alone Prediction Program (ASAPS) from the Australian Radio Prediction Service and IONCAP from the Institute for Telecommunication Services of the US Department of Commerce to quantify the possibility of HF communications and suggest suitable radio system design parameters. Similarly, predictions of meteor burst (MB) link performance are provided for comparison with available measurements so that comparisons may be performed with actual link operations. Finally, an HF/VHF radio system design is envisioned to meet polar communications requirements and follow-on work to develop and verify design details is recommended.

INTRODUCTION

HF Communications

The Division of Polar Programs (DPP) of the National Science Foundation (NSF) as well as the Naval Undersea Warfare Center (NUWC) of the US Navy share a common need for high-latitude radio communications for their respective constituents. In addition to satellite communications (SATCOM), HF skywave radio provides a viable long-range circuit for both voice and data. The DPP employs HF for regular communications between McMurdo Station and Christchurch, New Zealand as well as from McMurdo or Christchurch to intransit aircraft. HF links are also possible between the many US and international bases and semipermanent outposts. These links are depicted in Fig. 1. It provides a valuable technique for emergency communications with field parties operating from temporary encampments within several hundred miles of these established facilities. These short-range HF links employ near-vertical incidence skywave (NVIS) propagation paths which necessarily employ frequencies in the lower portion of the HF band combined with ray elevation angles approaching 90°.

The ongoing development of automatic link establishment (ALE) techniques has computerized the frequency-selection process at the cost of increased channel overhead and terminal sophistication. Real-time network operation and frequency management techniques are under development, with MIL-STD-188-141A providing the fundamental industry guide to guarantee operational interoperability between different vendor's products. NSF is evaluating the utility of ALE HF radio to meet its point-to-point, point-to-area, and ground-to-air communication requirements. The fundamental system design tradeoff for the use of HF radio is the maximum required transmit power versus ALE frequency-set selection and network operation. In other words, does the use of appropriate ALE frequency scan sets combined with the path diversity via relaying by a wide-area HF networks significantly reduce the transmit power required to support successful skywave communications? The objective of this study is to answer this system design question through the utilization of available environmental measurements, application of validated computer models, and the development of systems architecture.

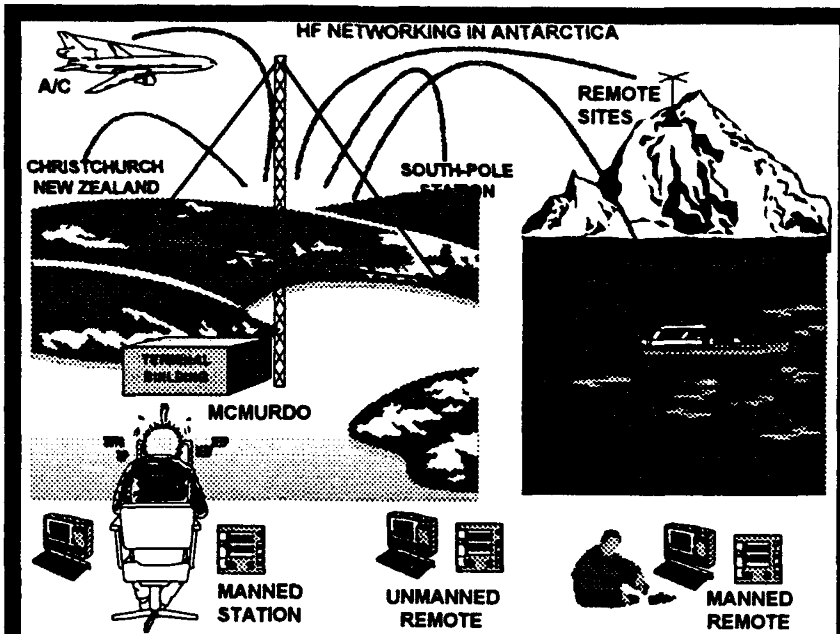


Fig. 1 DPP HF Links in Antarctica

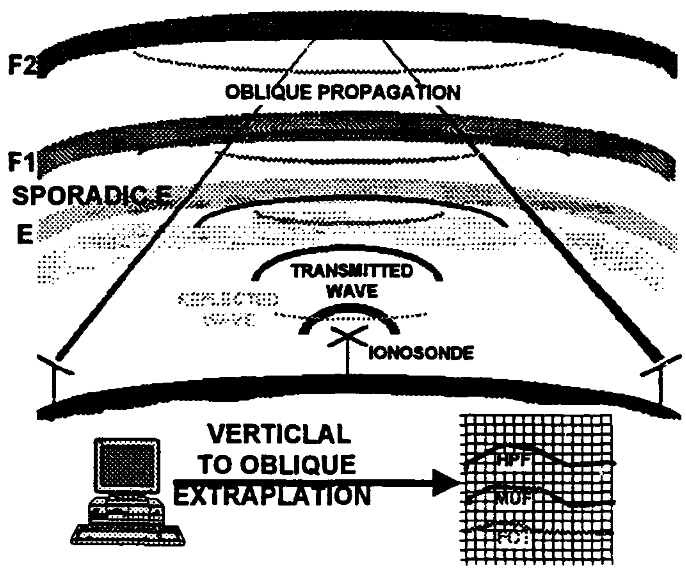


Fig. 2 Scott Base Ionosonde

An ionosonde operated at Scott Base in Antarctica has provided many years of nearly continuous vertical incidence measurements of critical frequencies, virtual reflection heights,

and oblique-incidence MUF factors. This data provides a valuable empirical basis for the validation of radio circuit models for HF link performance prediction in the polar environment, particularly for links whose midpoint is located above Scott Base (see Fig. 2). These predictions provide a useful analytic tool for link and network design inasmuch as frequency selection is concerned, but they fall short of establishing validated estimates of transmitter power requirements. Preliminary ALE operation has been demonstrated on several HF links between Antarctica, New Zealand, and Australia. The resulting multiple link performance records in combination with the Scott Base ionosonde data provides an important set of validation data for model predictions of required signal-to-noise ratio (SNR). In addition, they are directly usable for the derivation of path diversity gain and frequency/network management strategies to minimize transmitter power while minimizing message delay and maximizing throughput.

MB Communications

VHF MB radio may be feasible for point-to-point links up to 2000-km range or point-to-area and ground-air links below about 1000-km range as shown in Fig. 3. The principal advantage of MB radio is the use of a single frequency combined with the resilience of VHF ionospheric propagation in a disturbed ionosphere as compared to HF radio on equivalent paths. In particular, polar cap absorption (PCA) events have been shown to produce significant HF outages while VHF MB links have continued to operate. This result is due to the approximate proportionality of absorption to the inverse square of signal frequency, thus producing less absorption in the VHF then the HF bands.

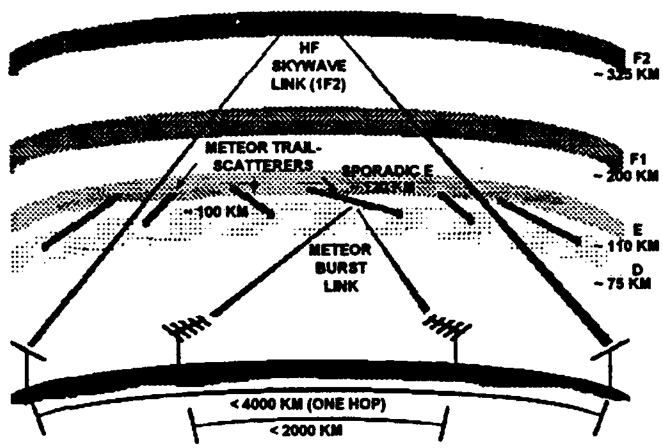


Fig. 3 Meteor Scatter and Ion Layers

Recently, Hadron MB terminals and five-element Yagi antennas were operated on a 1400-km link from McMurdo to Byrd Station. The objectives of this experiment were to accumulate experimental MB data for model validation and demonstrate MB link performance in Antarctica. This same equipment had been operated on a 600-km link in CONUS in 1989. In both cases, single five-element Yagi antennas were employed with 1-kW transmit powers. Recently, order of magnitude increase in link throughputs has been demonstrated by the Meteor Communications Corporation using adaptive antenna beamforming techniques at the receive site. These results are being repeated and enhanced by the application of beamforming techniques to both transmit and receive arrays as part of an ARPA program for the improvement of MB communications technology. Both point-to-point and point-to-area applications for high ERP MB link configurations are discussed in the pre-publication of the MILCOM'93 paper included in

Appendix F of this report. The recent availability of MB terminals from discontinued Government communications programs makes the acquisition of advanced MB technology attractive to the NSF and NUWC applications in Antarctica and elsewhere.

The Antarctic test of MB terminals demonstrated a persistent non-meteoric propagation mechanism, possibly sporadic E, which dominated link performance. Although this phenomena masked most, if not all, meteor trail-scatter events, it demonstrated nearly continuous VHF connectivity at a range of about 1400 km. Certainly, meteor scatter would have provided typical MB link throughput for the configuration employed had these enhanced modes not been present. Moreover, it suggests that lower antenna gain and/or transmitter power could have been used while maintaining acceptable communications. These values could be further reduced by the use of a high-gain adaptive antenna at the base station (e.g., McMurdo).

Contents

A detailed description of the extrapolation from ionosonde to oblique propagation modes is provided in the next section. The subsequent section presents meteor burst model predictions for the Byrd-McMurdo and CONUS links. A comparison of the CONUS predictions are made with the corresponding 1989 measurements. The final section summarizes these results from the perspective of Antarctic radio system design and describes the necessary follow-on efforts to finalize this design.

Appendices A and B document computer programs developed for NSF/NUWC to relate ionosonde data to the frequency availability for oblique propagation. Appendices C and D present results from this oblique propagation analysis. Appendix E contains the meteor burst prediction results and Appendix F contains a pre-publication copy of an Ionospheric Effects Symposium paper on an advanced meteor burst communication system test and demonstration.

HF LINK ANALYSIS

Ionosonde Data Analysis

Scott Base Ionosonde Data

Ionosonde data measured at Scott Base in Antarctica from the years 1970 through 1983 was available for the characterization of local ionospheric skywave propagation conditions. The data consisted of monthly tables of hourly values for several scaled parameters measured from ionosonde output traces. One data file was provided for each calendar year. Primarily, the data included the critical, or maximum, frequency f_v (MUF) for which the ionosphere would reflect a vertically-launched radiowave from one or more ionospheric layers. Ideally, the virtual reflection height h' would also be provided or, at a minimum, the scale factor for determining the basic MUF value for single-hop propagation to a fixed distance. The F2, F1, and E layers define the most important ionospheric altitude bands used for HF skywave radio and therefore are of significant importance in the analysis of ionosonde parameters as depicted in Figs. 2 and 3. For the F2 layer, a "MUF factor" M3000F2 (M_{F2}) is provided to convert the F2-layer critical frequency foF2 ("o" for ordinary wave) into the corresponding MUF values for a single-hip range of 3000 km. Note that MUF in scientific parlance refers to the maximum usable oblique frequency at a given time, not the 50% value from the distribution. At this point, we will refer

to this "basic MUF" value as the maximum propagating frequency extrapolated to a specified range from the mid-path ionosonde data and let the unmodified "MUF" to refer to the 50%-tile value.

The data before October 1977 included only F2 critical frequencies and basic MUF factors, with no parameters reported for F1- or E-layer activity and no reason provided for the absence of this data. Only a "C" qualifying letter, indicating that the measurement was impossible for some non-ionospheric reason, was reported for each hour in these cases. After October 1977, F2-, F1- and E-layer parameters are scaled and appear in the data files along with the appropriate virtual heights.

The data for each month and scaled parameter in a yearly file was presented in a single block. A block header specified the ionosonde site, the date, and the identity of the scaled parameter whose values immediately followed the header. Each scaled parameter in a block consisted of five character positions, three positions carried an integer number and the remaining two positions carried a descriptive and a qualifying letter. The scaled frequency values were presented in the data file in units of $10f_v$ MHz, with the heights given directly in kilometers and the basic MUF factors presented as $100M_f$. Many hours of various months and years showed no parameter values or explanatory letter. A complete description of the data format is provided in Appendix A.

Statistical Characterization

A FORTRAN 77 computer program called IONOSTATS was written to extract scaled parameters from any interval or set of fixed times from one or more yearly ionosonde data files. Once extracted, these values are converted to their scaled values and accumulated in counting bins. When all desired times have been accessed for each parameter, the counts are normalized by the total count of events across all bins. The resulting numerical density value for each scaled parameter represented the probability that the parameter attained a value in the corresponding bin in the given hour. Cumulative values over all hours for each parameter value, frequency, height, and factor, were also provided. In addition, density tables were also generated for the descriptive and qualifying letters. In this way, the user could determine the likelihood of measurement failure and the frequency of measurement error or uncertainty.

The IONOSTATS program was used to survey each of the 14 data files and determine the available scaled parameters as well as the corresponding values of the descriptive and qualifying letters (see Appendix A). For example, F2 critical frequencies typically bore the 'U' qualifying letter meaning uncertain numerical value and the 'F' descriptive letter indicating the probable occurrence of spread-F echoes (dispersive reflection). Since this effort focuses on oblique propagation, albeit including NVIS paths, no further IONOSTATS results are provided. In any case, the results presented in this report for NVIS links mimic the corresponding ionosonde results given the short link ranges involved.

Oblique Incidence

Extrapolation

Let f_v be the ionosonde-reported critical frequency for a vertically incident signal from some ionospheric layer at a virtual height h'. The corresponding basic MUF value f_{ob} for single-hop oblique propagation over a link with Great Circle path (GCP) length D and path midpoint located above the ionosonde may be given by:

$$f_{ob} = k(D)\, f_v \sec(\phi_o) \tag{1}$$

where the angle of incidence of the signal incident on a curved ionospheric layer is given by

$$\phi_o = \tan^{-1}\left[\frac{\sin(\theta_D/2)}{1+(h'/R_E)-\cos(\theta_D/2)}\right] \tag{2}$$

and

$$\theta_D = D/R_E \tag{3}$$

R_E is the earth's radius, and $k(D)$ is the secant correction factor that approximates the effects of ionospheric curvature. The geometry represented in these expressions is depicted in Fig. 4. The function $k(D)$ is plotted in Fig. 5.

The elevation angle θ_{el} measured from the horizon to the virtual reflection point and provides a means of estimating the usable portion of an antenna pattern during link design studies. From Fig. 4, this angle can be determined as

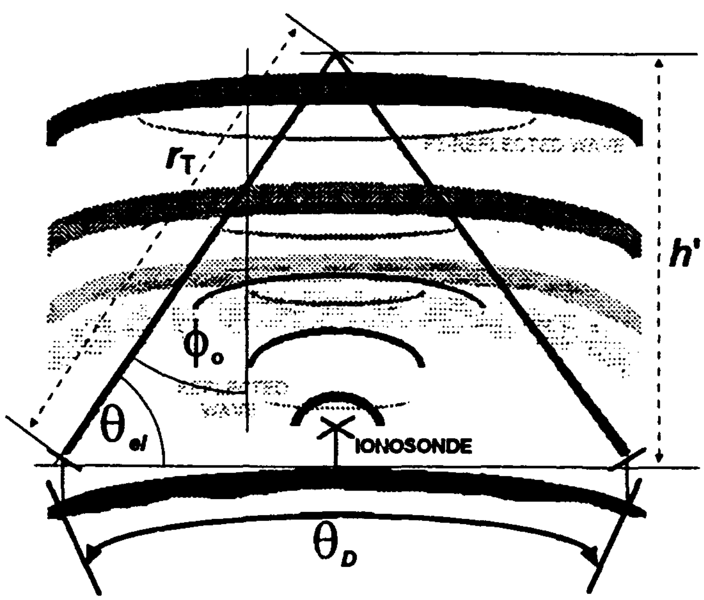


Fig. 4 HF Link Geometry

$$\theta_{el} = 180-\alpha-\theta_D/2 \tag{4}$$

where

$$\alpha = \cos^{-1}\left[\frac{r_T^2+(R_E+h')^2-R_E^2}{2r_T(R_E+h')}\right] \tag{5}$$

and

$$r_T = \sqrt{h'^2+2R_E[1-\cos(\theta_D/2)](R_E+h')} \tag{6}$$

When the virtual height is not available in the ionosonde data base, then it may either be computed from the corresponding basic MUF factor M_f or the average height of the layer may be

used (e.g., 325 km for the F2 layer). If the basic MUF factor is available, then the virtual height may be approximated by

$$h' = R_E\left[\frac{\sin(\theta_D/2)}{\tan(\phi_o)} + \cos(\theta_D/2) - 1\right] \tag{7}$$

where it is necessary to compute $\tan(\phi_o)$ from

$$\tan(\phi_o) = \frac{M_f\sqrt{1-\left(\frac{k(D)}{M_f}\right)^2}}{k(D)} \tag{8}$$

These equations are used by the IONOLINK computer program (see Appendix B) to determine the critical frequencies and elevation angles for one-hop oblique propagation in Antarctica with a path midpoint (reflection point) above the Scott Base ionosonde.

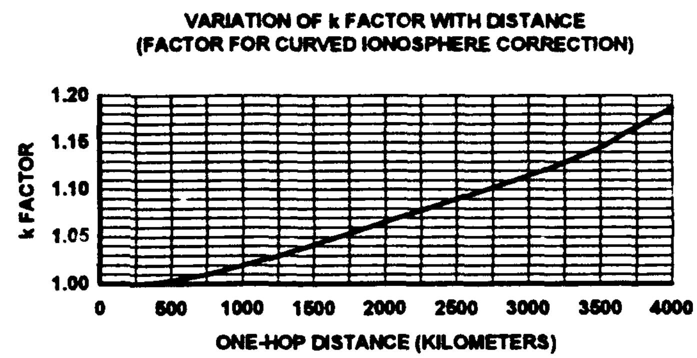


Fig. 5 k Value Versus Range D

For each hour in a for which the ionosonde data includes a legitimate scaled value (i.e., a value is provided), the IONOLINK program first computes the F2-layer basic MUF value for each range D input by the user, i.e., $f_{F2}(D)$. Next, it computes $f_{F1}(D)$ and $f_E(D)$. Since NVIS propagation may include 2-hop propagation from the E layer, IONOLINK also computes the two hop value $f_{2E}(D/2)$. Finally, the sporadic E layer (E_s) is considered for the computation of the one-hop value $f_{E_s}(D)$ and the two-hop value $f_{2E_s}(D/2)$. The basic MUF value, or link frequency f_L, for the given hour is then determined from

$$f_L = \mathrm{MAX}\{f_{F2}, f_{F1}, f_E, f_{2E}, f_{E_s}, f_{2E_s}\} \tag{9}$$

The f_L values are used to increment cumulative distribution bins which are normalized by the total number of usable ionosonde data hours in the chosen sample set. Typically, this sample set spanned all of the hours in a one-month period.

Appendix C contains skywave mode and basic MUF density plots for maximum sun and minimum sun periods at 50-, 200-, 1000-, and 2000-km link ranges. These periods were chosen to demonstrate the effect of solar-induced ionization on skywave link frequencies. These periods are roughly apparent from Fig. 6, which plots non-refraction solar zenith angle versus Universal Time (UT) for March, June, September, and December. The minimum sun period at Scott Base, Antarctica, corresponds to April through September and the maximum sun period corresponds to January through March and October through December. Results for both 1975 and 1979 are plotted in the appendix, although the 1975 results included scaled values exclusively for the F2 layer. The low values of average sunspot number (SSN) during the maximum sun period in 1975 (SSN = 19) and the minimum sun period (SSN = 24) may have

obviated the need for scaling of E- and F1-layer values. Thus, the modes and densities plotted on pages C-4 through C-20 show only basic MUF values produced by the F2 layer.

In 1979, the corresponding SSN values were 172 and 133, respectively. These higher values of SSN most likely produced greater ionization. This increased ionization would induce 1E and 1F1 modes as well as 1F2 modes and require scaling of the corresponding critical frequencies, virtual heights, and MUF factors. The mode density plots for 1979 show 1F1, 1E, and 1Es modes as well as 1F2 modes. In the minimum sun period, the 1979 50-km link (pg. C-30) shows a predominance of 1F2 and 1Es modes with diminutive F1- and E-layer effects. The corresponding frequency density plot for 50-km range (pg. C-31) was dominated by frequencies between 2 and 10 MHz with basic values apparent between 60 and 100 MHz. As link range increases to 2000 km (pg. C-37), the density values for the upper frequency bins increase into the 150-300-MHz range During the maximum sun period, the 1979 50-km link showed a dominance of F1 as well as F2 modes with a reduction of both Es and E modes in percentage of time. As link range is increased from 50- to 2000-km range, the percentage of 1F1, 1E1, and 1Es mode support increases significantly relative to 1F2 support for both minimum and maximum sun periods. The corresponding maximum sun MUF density values increase significantly relative to their corresponding values in the minimum sun period. At 2000-km range (pg. C-28), basic MUF values for the maximum sun period were found in the 150-300 MHz range for about 60% of the time.

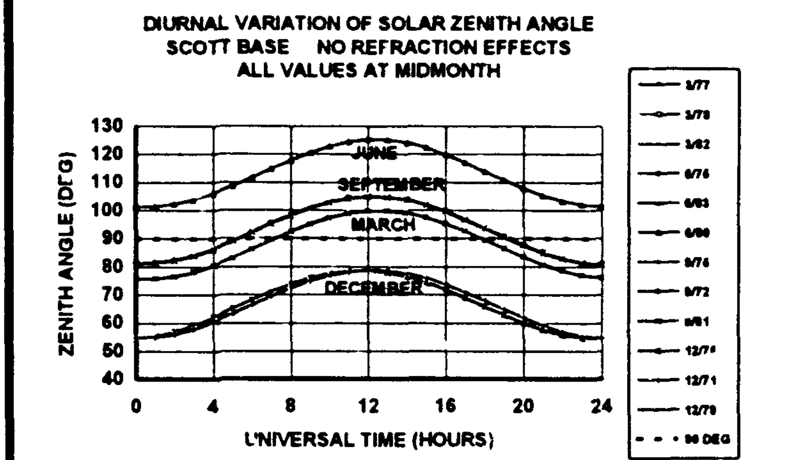


Fig. 6 Solar Zenith Angles

Measurement-Prediction Comparison

For the purposes of the model validation effort, an inverse interpolation was performed on the monthly cumulative distributions of basic MUF values for each hour. This interpolation was performed to estimate the basic MUF value associated with a particular probability of exceedance. For example, the optimum working frequency or FOT, corresponds to that basic MUF value which is exceeded in 90% of the days in the specified hour. Since actual cumulative bin counts were not likely to fall exactly on the 90%-tile value, an interpolation was required between adjacent counts to estimate the associated basic MUF value for the FOT.

A comparison was made between the ionosonde-extrapolated values of frequencies selected from the monthly cumulative distribution of hourly frequency availability and computer predictions from the IONCAP and ASAPS computer programs. These values corresponded to the lower decile, median, and upper decile points along the distribution. The lower decile values, or FOT, is the frequency exceeded for 90% of the month's days for a specified hour of

the day. In practice, the FOT is a system-dependent frequency and not a function of propagation conditions alone. Thus, at most 31 values were used to estimate each cumulative basic MUF-value distribution. Similarly, the standard MUF value exceeded for 50% of the month's days in the specified hour, and the HPF values, exceeded for only 10% of the month's days in the given hour. The objectives of this comparison were both to determine the relative prediction accuracy of the ASAPS and IONCAP programs and to validate computer model predictions in general.

In order to compare measurement and prediction for a wide range of ionospheric conditions, k the months of March, June, September, and December were selected to study the effects of solar zenith angle, χ, on link performance and model predictions. GFE sunspot data was then analyzed for these months over the 14-year period (corresponding to the available ionosonde measurements) to determine the minimum, maximum, and average values of monthly-averaged sunspot number (SSN). The resulting SSN values and the years in which they occurred for each month are provided in the table on page D-1 (Appendix D). The resulting solar zenith angles at Scott Base for these four months and three SSN values per month were plotted in Fig. 6. As expected for Scott Base (78° S latitude), the sun is below the horizon ($\chi > 90°$) for all of June and above the horizon ($\chi < 90°$) for all of December with the expected diurnal variation. Note that local time differs by about 11 hours from the Universal Times shown in the plot.

Overall, a survey of the plots presented in Appendix D suggests that:

(1) the ASAPS and IONCAP basic MUF values (FOT, MUF, HPF) are less than ±2 MHz in nearly all cases and are often closer than 0.5 MHz,

(2) both ASAPS and IONCAP predictions are within about ±3 MHz of ionosonde-extrapolated results for a majority of the hours and months shown, with many comparisons within 1 MHz,

(3) the predicted diurnal variation of FOT, MUF, and HPF values appears to track the corresponding measurements in a majority of the cases,

(4) predicted basic MUF values for both ASAPS and IONCAP were significantly below measurement-extrapolated values during maximum sunspot number and maximum sun periods but tracked the measurements as described in (1) through (3) when the solar zenith angle was a maximum (compare pp. D-149 to D-152 with Fig. 6), and

(5) changing numbers of ionosonde sample points produced oscillation in extrapolated basic MUF values (e.g., pp. D-71 through D-74) while too few values resulted in constant extrapolated basic MUF values in some cases (e.g., pp. D-62 and D-63).

(6) an anomaly was discovered in which the IONCAP-predicted basic MUF value would decrease slightly with increased link range from 50 to 200 km, a result not possible with the algorithms employed to extrapolate the Scott Base ionosonde data and not observed in the ASAPS predictions.

These results suggest that either IONCAP or ASAPS may be employed to predict approximate basic MUF values for one-hop Antarctic skywave links straddling Scott Base during minimum sun regardless of the SSN value or during maximum sun for minimum SSN values. During maximum sun and maximum SSN values, the extrapolated basic MUF values are much higher than the corresponding predictions. This result occurs because neither ASAPS nor IONCAP predict F1, E, or Es modes during these maximum sun/SSN periods although these modes are apparent in the ionosonde extrapolated basic MUF measurements.

ASAPS and IONCAP path loss measurements were compared for a subset of the results provided in Appendix D. These values differed by less than 2 dB, suggesting similar loss mechanism models are employed in both models. Since the ASAPS source code was unavailable, a more detailed evaluation of path loss algorithms was not possible. Given effectively equivalent path loss calculations, the noise level and antenna gain values needed to complete link SNR performance predictions may be identical for both models. IONCAP, however, employs link reliability and service probability values not computed by the ASAPS program which provides only median SNR values.

This analysis did not consider the lowest usable frequency (LUF), computed as a system-dependent value accounting for absorption, antenna gain, noise levels, etc. In the absence of this prediction, the lower bound for link-usable frequencies cannot be determined. Thus, although the extrapolated measurements indicate basic MUF values as high as 150 MHz, the minimum usable frequency in the HF band is unknown. If significant absorption occurs simultaneously with the levels of ionization required to support strong F1- and E-layer reflections, than the lower HF band may be unusable at a minimum. The analysis of cosmic noise absorption data at Scott Base would permit an estimate of two-way skywave path absorption for the estimation of conservative LUF values for nominal HF system designs.

METEOR BURST LINK ANALYSIS

Objectives

MB radio provides a viable communications technique for on-continent point-to-point links between base stations and point-to-area links between base stations and field parties. In recognition of these potential MB applications, a meteor burst link was operated between Byrd Station and McMurdo in December of 1992. The objectives of this link test were to verify effective MB link operation in Antarctica and provide a set of validation measurements for comparison with available prediction techniques.

Approach

Link Performance Measurements

The 1992 Antarctic full-duplex (FDX) MB link consisted of a 1460-km path between Byrd Station (80° S, 120° W) and McMurdo (78° S,167° W) operating on 42.03 and 48.75 MHz. Each link site employed corresponding horizontally-polarized five-element Yagi antennas for transmit and receive, with each antenna placed at a height of about 9 m above ground (3/2 wavelength at 48.75 MHz), 1-kW transmit power, and a 9.6 kbps channel rate. Half-rate Golay forward error correction (FEC) was employed for the transmission of 120-character messages in

20-character packets. A required received power of -110 dBm was assumed for no-FEC reception and -114 dBm was assumed for FEC reception based on previous work. Both link terminal transmissions consisted of contiguous seven-packets sequences with no channel time required for probe signals.

The Antarctic link measurements constituted the third test of the Hadron terminal equipment. The first test, performed during peak solar activity in 1989, employed a 600-km mid-latitude link oriented from northeast to southwest with otherwise similar link parameters. Results from this test have been presented in this report to provide an additional measurement-prediction comparison. Since only a few of these link test hours were uncontaminated by interference, only a small number of measured values are available. Therefore these results should be used only as an indication of model accuracy at mid-latitude, and not a validation of model accuracy in Antarctica. These predictions do, however, indicate the magnitude of measured link throughput values expected for the 1989 test link. Since the Antarctic link was operated at more than twice the 1989 link range, Antarctic link throughput should exceed the 1989 results. This increased range resulted in increased forward scattering angles for most usable trails and the concomitant increase in received signal duration.

METEORLINK Predictions

The METEORLINK computer program was used to predict Antarctic link performance. The METEORLINK computer program is a physical model of a meteor scatter radio link originally developed in 1988. Since that time, METEORLINK has undergone numerous modifications to improve prediction accuracy and maximize its utility as a link-diagnostic tool. The purpose of the physical model is not only to provide link performance predictions, but also to enable diagnostic analysis of the dominant meteor scatter phenomena affecting link performance. An important function of a physical model, such as METEORLINK, is the determination of the arriving meteor flux which is both suitably located and oriented to contribute to the link-usable meteor rate (MR) and DC values. For example, Fig. 7 is a contour plot of the combined sporadic meteor flux measured by radars in Kazan, Russia and Mogadishu, Somalia. These values are shown in ecliptic coordinates, in which 0° ecliptic latitude is measured from the intersection of an earth-concentric sphere and the plane of the earth's orbit. In the figure, ecliptic longitude has been measured positively from the apex of the earth's way (earth's orbital direction) toward the sun with 180°

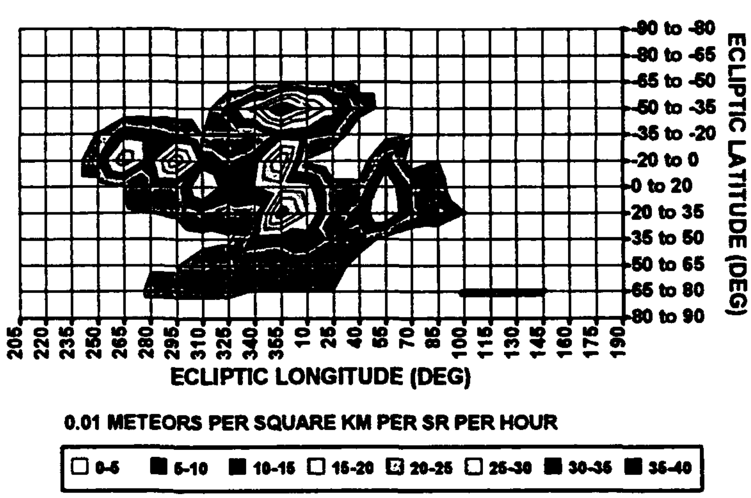


Fig. 7 Sporadic Meteor Flux in February

corresponding to the antapex direction. Clearly, most sporadic meteor radiants approach from the apex direction and thus maximize mid-latitude link performance at about 6 AM local time.

As the meteoroid descends into the atmosphere, it collides with atmospheric particles which heat the meteor and boils atoms from its surface. These freed atoms collide with atmospheric particles, producing the free electrons that form the ionized meteor trail used for meteor scatter. The speed of the meteor is imparted to these electrons, which rapidly diffuse outward until further collisions slow their movement. This rapid radial expansion of the trail creates the initial trail radius, which determines the strength of the initial trail-scattered signal. This expansion occurs within milliseconds of the meteor's passage of a fixed point. After this time, the trail expands radially due to normal ambipolar diffusion until electron attachment and upper atmospheric winds completely disintegrate the ion trail.

If the meteor trail is oriented in a plane tangent to an ellipsoidal surface whose foci are located at the transmit and receive antennas, then specularity is satisfied and the maximum signal is scattered toward the receiver. The criterion for coherent trail scatter on the MB link is equivalent to requiring that the sum of all radiowaves scattered from the trail differ by less than half a carrier wavelength (λ). In symbols,

$$\left|(r_{12}+r_{21})-(r'_{12}+r'_{21})\right| \leq \lambda/2$$

where the r-values are the radiowave path lengths shown in Fig. 8. This criterion defines the portion of the meteor trail lying within the central Fresnel zone, which contributes the majority of the trail-scattered signal at the receiver. Meteor trails meeting this criterion (approximately) are defined to be observable on the MB link, independent of the contribution of the trail to the link MR and DC values. As the trail expands due to diffusion, more and more trail electrons violate the coherent scatter criterion and the RSL decays exponentially.

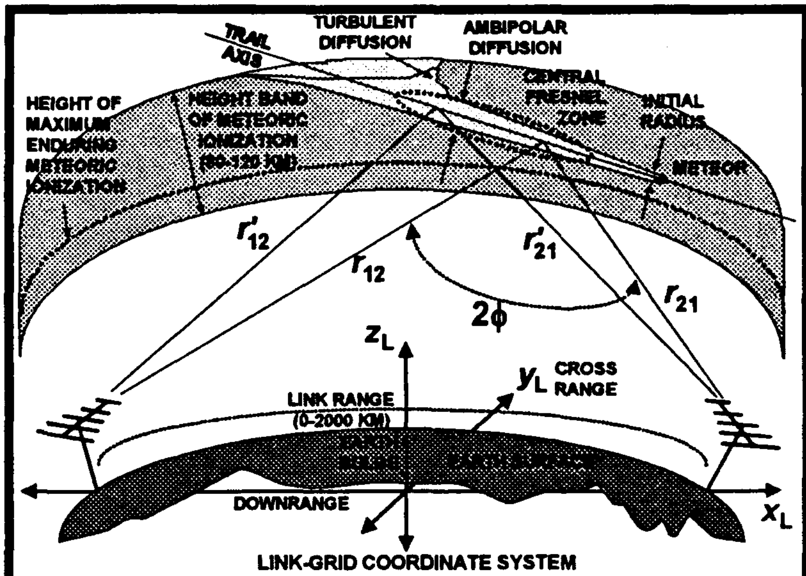


Fig. 8 Criteria for Coherent Trail Scatter

If the trail-scattered signal endures for more than about 400 ms, upper atmospheric winds distort the trail sufficiently to force coherent scatter from two or more different portions of the trail. In this case, the resulting RSL exhibits multipath fading which reduces the available channel bandwidth and somewhat reduces the burst DC contribution. Similarly, a small number of enduring trails are not originally oriented for coherent scatter but are distorted by winds until one or more trails segments are forced into a suitable scattering geometry. The trail-scattered signals produced by these *nonspecular* events contribute little to the overall link performance. Since these trails do not have initial orientations corresponding to a linear extension of radar-measured meteor flux data (e.g., Fig. 7), and METEORLINK does not yet contain a global high-

altitude wind model, the negligible contribution provided by the nonspecular events are not included in predicted link MR values.

Link-Usable Trails

The existence of a link-observable trail offers the possibility of a usable trail-scattered signal. If a trail-scattered signal is to be detected above the noise level measured in a receiver, then the path loss from the transmit to receive antennas must not exceed some maximum value. For effective communications, the signal must exceed the noise level by an sufficient amount to produce a usable signal-to-noise ratio (SNR) for acceptable modem performance. The resulting maximum allowable path loss (MAPL) value is a function of the transmitted power, the required received power, and the antenna gain product at a specified point in the link common volume. This MAPL value determines the minimum linear electron density (line density q^*) required along the trail axis to produce a link-usable trail-scattered signal above the receiver's noise threshold.

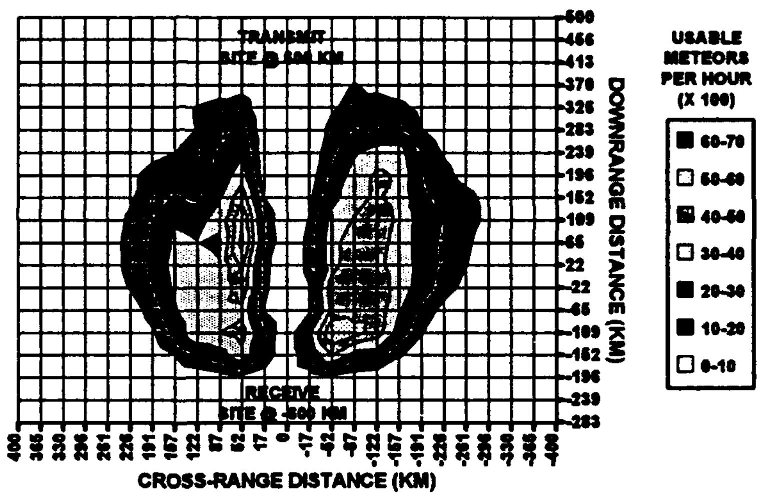


Fig. 9 Link-Usable Meteor Rates on a 1200-km Link

The electron line density q^* is a function of the characteristics of the trail-scattering process as well as the orientation of the trail and the corresponding MAPL value. If the q^* value is distributed in a large enough volume so that the individual electrons serve as independent, single scatterers of the incident radiowave, then the trail is termed *underdense* scatterer. On the other hand, if the electron volume density is so high that the electrons mutually interact, than the trail is characterized as an *overdense* scatterer. Of course, there is a *transition* region in which trails exhibit both types of scattering behavior during their lifetimes. Certainly, all link-usable trails must ultimately become underdense if not destroyed by turbulent winds.

The electron line density q at a given point along a meteor trail is determined predominantly by the meteor's mass, the atmospheric density at the trail-scatter point, the angle made by the trail with the zenith, the material that composes the meteor, and the meteor's speed. Given the MAPL value at a specific trail-scatter point, a specific trail orientation through that point, the minimum required q-value q^*, and estimates of meteor substance, speed, and atmospheric density, the minimum required meteoroid mass m_q^* needed to produce q^* can be computed. The number of meteoroids exceeding mass m in the neighborhood of the earth has been empirically shown to satisfy

$$N_m = c_m m^{-s},$$

where s is a function of arrival direction. The arrival rate of meteors exceeding mass m_q^* is therefore proportional to m^{-s}, where the proportionality coefficient includes the appropriate flux density value (see Fig. 7) for the corresponding trail orientation. An observable meteor trail with an electron line density $q > q^*$ is called a link-usable trail. The occurrence rate of link-usable meteor trails is called the usable meteor rate, or meteor rate (MR) for brevity, and constitutes a vital MB link performance measure. Similarly, integrating the DC contribution from each usable trail yields the link DC value. Fig. 9 plots the MR contributions for a 1200-km north-south link in February at 6 AM local time. The trough along the link's Great Circle path (GCP) is to the negligible contribution from trails tangent to an earth-concentric sphere.

Results

METEORLINK predictions were performed with and without FEC for both FDX-link frequencies in February and July as well as December. The February and July predictions bound the seasonal variation expected during the year. The link-usable MR, DC, and 120-character message throughput values are plotted versus universal time in Appendix E. The throughput results on pages E-4, E-7, E-10, and E-13 include hourly values from the 1989 Hadron terminal test and the corresponding METEORLINK-based predictions. Clearly, the 1989-link predictions lie within the available measured values.

The Antarctic predictions are expected to be similarly related to Antarctic link measurements. Preliminary survey of the Antarctic link measurements, however, have indicated a predominance of continuous link connectivity not possible via meteor scatter for the link power budget available for the test. Near-continuous sporadic E propagation was indicated, but no analysis of the MB link measurements was available. Since the continuous connectivity certainly provides "best case" link performance, albeit not due to meteor scatter propagation, the METEORLINK predictions presented in Appendix E represent an expected lower bound on benign link performance.

High-ERP MB Communications

The Advanced Research Projects Agency (ARPA) is conducting tests of a high-ERP meteor burst communications link between Verona, NY, and Charleston, SC, with live demonstration facilities planned for a location in Arlington, VA, beginning in July, 1993. The demonstration link is expected to yield average hourly message-bit throughputs between 1 and 10 kbps as compared to nominal link designs that yield 100 to 1 kbps values under minimum meteor flux conditions. Assuming eight-bit characters, these increased link throughputs yield 3750 to 37500 120-character messages per hour. This VHF technology has a potentially significant role in providing primary base-to-base communications as well as serving as HF backup during periods of skywave blackout. A complete description of the ARPA high-ERP MB Link Experiment (HEMBLE) is provided in Appendix F.

CONCLUSIONS & RECOMMENDATIONS

Study Conclusions

The IONCAP and ASAPS computer programs have been shown to predict propagating frequencies extrapolated from Scott Base ionosonde data. The path loss predicted by both programs also appear to agree closely (within 3 dB), but IONCAP provides reliability calculations not found in the ASAPS model. This results suggests that these computer programs provide adequate tools for HF network design. They also provide ionosonde data analysis software, combined with other environmental measurements such as sunspot number and auroral activity measures, which could be modified to serve as an effective on-line frequency selection tool for Antarctica.

Preliminary IONCAP predictions made for point to area applications with 0 dBi constant gain antennas and a required 90% reliability indicate that transmitter powers of 100 W are required for point-to-area links in the vicinity of Scott Base. This result ***does not*** include the advantage gained from HF relaying, by replacing an inefficient NVIS link with two (or more) efficient long-range relay links. If the Scott Base ionosonde results are characteristic of the Antarctic continent, then this result would apply throughout the region. Employing directive antennas on point-to-point links would produce a lower required maximum power for these links, albeit the higher power value would nevertheless still be required for science parties employing 0 dBi (NVIS) antennas. Lower antenna gain than 0 dBi for science party operations would require a corresponding dB increase in transmitter power above the 100 W value to achieve the 90% reliability value. This conclusion must be validated using the ALE HF radio received signal measurements currently in operation in Antarctica. Combining these measurements with the IONCAP predictions and extrapolated ionosonde data would provide the best possible basis for transmit power selection in an ALE HF environment.

Meteor burst predictions for the McMurdo-Byrd link show effective emergency communications to science teams in Antarctica. Measurements on this link have demonstrated a preponderance of possible E-layer reflections. There is no doubt that meteor scatter will provide about 10 bps throughput to science parties at VHF and in excess of 100 bps throughput between base stations. These numbers may be increased by an order of magnitude by employing beamforming techniques and large antenna arrays at the base stations. The small, relatively inexpensive MCC terminal (MCC-545) designed for vehicle tracking applications provides an ideal science party remote terminal, while Government disposition of MCC-520, 6520, and 6560 terminals from other programs provides a low-cost means of acquiring master stations for base installations.

System Design Recommendations

The 100-W minimum transmitter power requirement must be validated by more exhaustive link predictions throughout Antarctica. This analysis should be based on a validation of power levels using existing data. This data, taken from an ALE HF radio network being operated in Antarctica with points in New Zealand and Australia, must be used to evaluate the path diversity gain inherent in HF relaying. Network operation and frequency management techniques developed from this analysis would then be implemented in controlling software for each HF

radio. Thus, science party and base station radios may relay messages from other science parties to the desired station. This capability may even lower power requirements below the 100-W value, and replaces brute force power requirements with intelligent radio use.

The 100-W result assumes normal background atmospheric noise. If the background noise is higher, at McMurdo for example, than either the HF receive system must be remoted to an electromagnetically quiet site or the science party transmit powers must be correspondingly increased above the 100 W value. Higher background noise must be expected aboard an aircraft intransit to McMurdo. Thus, the transmitter power required for ground-air operations should be chosen large enough to defeat aircraft noise or the aircraft noise should be reduced after a careful measurement program. This program would involve noise measurements taken on MAC flights (or other flights of opportunity) within CONUS as well as essential aircraft antenna pattern modeling. This result may be mitigated to some extent by the use of directive antennas at McMurdo (or other base) pointing in the known direction of aircraft approach.

The available Antarctic ionospheric environmental data must be correlated with ionosonde data to determine the characteristics of HF link disruption and outage as well as the role of VHF communications (e.g., meteor burst) during these periods. Thus, base, science team, and aircraft may be equipped with VHF (probably meteor burst) assets to ride out ionospheric disturbances that prevent HF propagation at any band frequency. The objective of this study would be to verify the utility of VHF during these periods and recommend a system (network) design.

The HF and VHF radio networks would be integrated into a single regional network, using environmental data and communicant locations to optimally route message traffic. Techniques from fuzzy logic control would be considered to provide smart use of radio resources available at any time. The objective of terminal (laptop PC) interface would be to make all relaying functions invisible to the user and serve solely as a message I/O device. The technology required to establish this network exists but must be intelligently chosen, integrated, and tested. Otherwise, the piecemeal development of this communication system in the absence of an integrated approach will force higher transmit powers in a brute force attempt to operate single essential links. SAIC, NUWC, and NSF have the experience, data bases, and capabilities necessary to design, develop, deploy, and verify such an integrated communications network.

APPENDIX A IONOSTAT COMPUTER PROGRAM

A.1 DESCRIPTION AND INSTALLATION

IONOSTAT is a Microsoft FORTRAN 5.0 computer program developed and executed on a Gateway 2000 486/33-MHz PC. The program was written and debugged using the Power Workbench (PWB) development tool from Microsoft (MS) which is available with its FORTRAN product. MS-FORTRAN 5.0 employs ANSI FORTRAN 77 as well as several additional features for compatibility with VAX FORTRAN available from the Digital Equipment Corporation. The purpose of the IONOSTAT program is to accumulate numerical densities for the parameter values, qualifying letters, and descriptive letters provided in the "NEW URSI" data format as published in International Council of Scientific Unions Panel on World Data Centers "GUIDE to the WORLD DATA CENTER SYSTEM", part 2. These parameters include hourly junction frequencies (JFs), "standard" maximum usable frequency (MUF) multipliers, and ionospheric reflection heights (virtual heights), for the each of the observed ionosperhic layers.

IONOSTAT consists of a single source code module IONOSTAT.FOR which is compiled and linked by the PWB tool into IONOSTAT.EXE. Proper use of the MB-PWB tool is beyond the scope of this appendix. The executable image is invoked at the user prompt from drive C by the command:

C>**IONOSTAT**

where the highlighted and underlined text indicates user entry. The "C>" in this example is displayed by the PC. The program then asks the user for the name of the desired IONOSTAT input file with the following prompt:

Type name of input file without extension ".INP"

The user then types the name of the input file without the trailing (.) or file extension. The IONOSTAT program *assumes* that the input file extension is ".INP". For example, if the user's input file is called ION1970.INP and it resides in directory "INPUT" on drive "D", then the user would respond to the prompt with

D:\INPUT\ION1970

and the IONOSTAT program would automatically read file ION1970.INP in the indicated directory.

A.2 INPUT FILE DESCRIPTION

A.2.1 IONOSTAT Input File

The user-input file must be created using a standard ASCII editor. IONOSTAT reads this input file in a format-free format, so exactly one comma (,) or one or more spaces may be used to delimit entries. For example, consider the following example input file:

SCOTT BASE
1, 1, 1, 1
24, 31, 14, 2000
T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T
T, T, T, T, T, T, T, T, T, T, T, T
T
T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T
T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T
10, 20.0, 50.0, 100.0, 200.0, 400.0, 600.0, 800.0, 1000.0, 1500.0, 2000.0
2.0, 30.0, 56, T
0.0, 600.0, 60
0.0, 90.0, 60
1, T, 0.0, 12.0, 60
2, F, 0.0, 30.0, 60
3, F, 0.0, 30.0, 60
4, T, 2.0, 4.0, 50
5, F, 0.0, 600.0, 60
6, F, 0.0, 600.0, 60
7, T, 0.0, 60.0, 60
8, F, 0.0, 30.0, 60
9, F, 0.0, 10.0, 50
10, F, 0.0, 600.0, 60
11, T, 150.0, 600.0, 45
12, T, 0.0, 5.0, 25
13, F, 1.0, 30.0, 60
14, T, 90.0, 150.0, 60
15, F, 0.0, 600.0, 60
16, T, 0.0, 10.0, 50
17, F, 1.0, 30.0, 60
18, T, 0.0, 5.0, 25
19, F, 1.0, 30.0, 60
20, T, 90.0, 190.0, 20
21, F, 1.0, 30.0 , 60
22, T, 0.0, 5.0, 25
23, F, 0.0, 10.0, 50
24, F, 0.0, 600.0, 60
25, F, 1.0, 30.0, 60
26, T, 0.0, 16.0, 40

27, F, 1.0, 30.0, 60	39
28, F, 1.0, 30.0, 60	40
29, F, 1.0, 30.0, 60	41
30, F, 1.0, 30.0, 60	42
T	43
D:\NUWCION\67Q70.NEW	44
D:\NUWCION\67Q71.NEW	45
D:\NUWCIUN\67Q72.NEW	46
.	.
.	.
.	.
D:\NUWCION\67Q??.NEW	68

Each record (line) is shown numbered to the right of the input values to provide an index for reference to each item in this description. These numbers must *not* appear in the user-input file or an input error will occur. A description of each input value referenced by these numbers is provided in Table A-1.

A.2.2 IONOSONDE Data File Format

The "NEW URSI" data format as published in International Council of Scientific Unions Panel on World Data Centers "*GUIDE to the WORLD DATA CENTER SYSTEM*", *part* 2, defines the format of the ionosonde data input files. Although this format includes hourly median, upper/lower quartile, and upper/lower decile values derived for each parameter, none of these entries were provided in the data files provided as GFI for this study. The program should be capable of reading these values without failure, although it does not provide these values in its output.

Data for each parameter during one month form a physical block of fixed length 4800 bytes, which comprise 40 records each of length 120 bytes. The first record identifies the station, month of observation, and the parameter recorded. Subsequent records contain the actual data in the form of 24 groups of 5 characters representing values for the 24 hours of the day. Each 5 character group is coded using the rules laid down in UAG-23. Data for a year form a file within which the order of the blocks must follow time order. The order of the parameters within the file is not significant. The format of each physical block is provided in Table A.2.

Note that definitions for parameters I and I(xxx), records 41 and 42, respectively, were not found in UAG-23. These values were not required for the analysis performed on HF links in study for which IONOSTAT was developed.

Table A.1 Input Variable Descriptions for IONOSTAT Program

INPUT FILE ROW NUMBER	ITEM NUMBER IN ROW	FORTRAN VARIABLE TYPE	DESCRIPTION	TYPICAL VALUES
1	1	CHARACTER*20	Name of IONOSONDE station used to find the start of each month's data records	SCOTT BASE
2	1	INTEGER*4	First hour in time interval for bin-accumulation	1
"	2	"	First day in time interval for bin accumulation	1
"	3	"	First month in time interval for bin accumulation	1
"	4	"	First year in time interval for bin-accumulation	1970
3	1	INTEGER*4	Last hour in time interval for bin-accumulation	24
"	2	"	Last day in time interval for bin accumulation	31
"	3	"	Last month in time interval for bin accumulation	12
"	4	"	Last year in time interval for bin-accumulation	1972
4	1-25	LOGICAL*1	Use/ignore MASK for up to 25 years of ionosonde data files, one file per year, e.g., 1970 - 1972	T or F for each entry
5	1-12	LOGICAL*1	Use/ignore MASK for up to 12 months of ionosonde data for each year (file), 1 through 12	T or F for each entry
6	1	LOGICAL*1	Logic switch for program IONOLINK, not used in program IONOSTAT: T creates hourly FOT, MUF (standard), and HPF statistics for oblique HF links, F creates same density tabulations	T or F ignored
7	1-31	LOGICAL*1	Use/ignore MASK for up to 31 days of ionosonde data for each month (1 through 31)	T or F for each entry
8	1-24	LOGICAL*1	Use/ignore MASK for up to 24 hours of ionosonde data for each day (1 through 24)	T or F for each entry

Table A.1 Input Variable Descriptions for IONOSTAT Program (Continued)

INPUT FILE ROW NUMBER	ITEM NUMBER IN ROW	FORTRAN VARIABLE TYPE	DESCRIPTION	VALUES
9	1	INTEGER*4	Number of oblique path lengths for IONOLINK, *not* used in program IONOSTAT (10 MAX)	<u>10</u>
9	2-11	REAL*4	Oblique path lengths (km) for IONOLINK, *not* used in program IONOSTAT (10 values MAX)	<u>0.0</u> to <u>4000.0</u>
10	1	REAL*4	Lower frequency limit (MHz) for IONOLINK-computed FOT, MUF, & HPF values, <u>not</u> used in program IONOSTAT	<u>2.0</u>
"	2	REAL*4	Upper frequency limit (MHz) for IONOLINK-computed FOT, MUF, & HPF values, *not* used in program IONOSTAT	<u>60.0</u>
"	3	INTEGER*4	Number of frequency bins for IONOLINK-computed FOT, MUF, & HPF values, *not* used in program IONOSTAT (60 MAX)	<u>56</u>
"	4	LOGICAL*1	Logical switch to turn off sporadic E layer in IONOLINK analysis, *not* used in program IONOSTAT	<u>T</u> or <u>F</u>
11	1	REAL*4	Lower height limit (km) for IONOLINK-computed FOT, MUF, & HPF values, *not* used in program IONOSTAT	<u>0.0</u>
"	2	REAL*4	Upper height limit (MHz) for IONOLINK-computed FOT, MUF, & HPF values, *not* used in program IONOSTAT	<u>600.0</u>
"	3	INTEGER*4	Number of height bins for IONOLINK-computed FOT, MUF, & HPF values, *not* used in program IONOSTAT (60 MAX)	<u>60</u>

Table A.1 Input Variable Descriptions for IONOSTAT Program (Continued)

INPUT FILE ROW NUMBER	ITEM NUMBER IN ROW	FORTRAN VARIABLE TYPE	DESCRIPTION	VALUES
12	1	REAL*4	Lower antenna elevation angle limit (deg) for IONOLINK-computed FOT, MUF, & HPF values, *not* used in program IONOSTAT	0.0
"	2	REAL*4	Upper antenna elevation angle limit (deg) for IONOLINK-computed FOT, MUF, & HPF values, *not* used in program IONOSTAT	90.0
"	3	INTEGER*4	Number of angle bins for IONOLINK-computed FOT, MUF, & HPF values, *not* used in program IONOSTAT (60 MAX)	60
13, 14, 15, 19, 20, 24, 25, 28, 29, 30, 31, 33, 34, 37, 38, 39	1	LOGICAL*1	Logical switch to turn on analysis for the corresponding ionosonde-scaled-frequency parameter codes described in Section A.2.2. A "T" tells the IONOSTAT program to process the parameter, not processed if "F".	T or F
"	2	REAL*4	Minimum value of frequency to be used in density accumulation bins	2.0
"	3	REAL*4	Maximum value of frequency to be used in density accumulation bins	30.0
"	4	INTEGER*4	Number of frequency bins to be used in density accumulation bins	28
16, 21, 35, 40	1	LOGICAL*1	Logical switch to turn on analysis for the corresponding ionosonde-scaled-factor parameter codes described in Section A.2.2. A "T" tells the IONOSTAT program to process the parameter, not processed if "F".	1 T or F
"	2	REAL*4	Minimum value of factor to be used in density accumulation bins	2.0
"	3	REAL*4	Maximum value of factor to be used in density accumulation bins	4.0
"	4	INTEGER*4	Number of factor bins to be used in density accumulation bins	20

Table A.1 Input Variable Descriptions for IONOSTAT Program (Continued)

INPUT FILE ROW NUMBER	ITEM NUMBER IN ROW	FORTRAN VARIABLE TYPE	DESCRIPTION	VALUES
17, 18, 22, 23, 26, 27, 32, 36	1	LOGICAL*1	Logical switch to turn on analysis for the corresponding ionosonde-scaled-height parameter codes described in Section A.2.2. A "T" tells the IONOSTAT program to process the parameter, not processed if "F".	1 T or F
"	2	REAL*4	Minimum value of height to be used in density accumulation bins	0.0
"	3	REAL*4	Maximum value of height to be used in density accumulation bins	600.0
"	4	INTEGER*4	Number of height bins to be used in density accumulation bins	60
41, 42	1	LOGICAL*1	Logical switch to turn on analysis for the corresponding ionosonde-scaled parameter code as described in Section A.2.2. A "T" tells the IONOSTAT program to process the parameter, not processed if "F".	T or F
"	2	REAL*4	Minimum value of parameter to be used in density accumulation bins	0.0 (?)
"	3	REAL*4	Maximum value of parameter to be used in density accumulation bins	600.0 (?)
"	4	INTEGER*4	Number of parameter bins to be used in density accumulation bins	60 (?)
43	1	LOGICAL*1	Logical switch to have densities on total elapsed time or elapsed time for which ionosonde data was possible, i.e., no equipment failure (qualifying letter "C")	T or F
44-68	1	CHARACTER*20	Ionosonde data filenames, including drive and subdirectory, if not the same as IONOSTAT.EXE, up to 25 filenames may be provided	See Section A.2.1 for examples

Table A.2 Ionosonde (New URSI) Data Format

Record	Columns	Description
1	1-20	Station name
1	21-25	Station code
1	26-29	Standard time meridian of the station (e.g. 150W, 90E, etc., with 000W or 000E = UT)
1	30- 33	Geographic co-latitude in tenths of a degree
1	34- 37	Geographic East longitude in tenths of a degree
1	38- 41	Year
1	42- 43	Month
1	44- 45	Parameter code (See UAG-23 characteristic code)
1	46-120	Spare
2	24 X 5-character code	Hourly data for the first day of the month (i.e. foF2 values - 078 R, 080 , etc.)
3	24 X 5-character code	Hourly data for the second day of the month (i.e. foF2 values - 078 R, 080 , etc.)
.	24 X 5-character code	.
.	24 X 5-character code	.
.	24 X 5-character code	.
32	24 X 5-character code (if available)	Hourly data for the thirty-first day of the month (If less than 31 days, blank fill.)
33		Medians
34		Median Count
35		Upper Quartile
36		Lower Quartile
37		Upper Decile
38		Range
39		Lower Decile
40		Spare

Not all of the 5-character scaled-parameter values were reported for each hour of the 15 years of Scott Base ionosonde data provided for the study. In this case, blank fill was used as a place holder. Note that the 15 files provided for this study were 67Q58.NEW, 67Q70.NEW, 67Q71.NEW, ..., 67Q83.NEW. None of these files included rows 33-40 in the monthly data blocks for each parameter. The IONOSTAT program should be able to read these values if present without disturbing normal execution. If N parameters have been scaled, then there will be N blocks for each of the months contained within a single file. For the standard" N = 14 parameters, the ionosonde data file should be organized as shown in Table A.3. A complete description of the parameter codes, descriptive, and qualification letters summarized in Table A.4a, b, and c, respectively, can be found in UAG-23 [].

Table A.3 Ionosonde Data File Organization

Block	Month	Parameter (Characteristic)	Numeric code
1	January	foF2	00
2	January	M(3000)F2	03
.	.	.	.
.	.	.	.
.	.	.	.
13	January	fxI	51
14	January	fmI	52
15	February	foF2	00
16	February	M(3000)F2	03
.	.	.	.
.	.	.	.
.	.	.	.
167	December	fxI	51
168	December	fmI	52

Table A.4a Parameter Codes

Description	Parameter Codes and Meaning					
F2 layer	00-foF2	01-fxF2	02-fzF2	03-M(3000)F2	04-h'F2	05-hpF2
F1 layer	10-foF1	11-fxF1	13-M(3000)F1	14-h'F1	16-h'F	
E layer	20-foE	22-foE2	24-h'E	26-h'E2		
Es layer	30-foEs	31-fxEs	32-fbEs	33-fEs	34-h'Es	
Other	40-foF1.5	42-fmin	43-m(3000)F1.5	44-h'F1.5		
Spread	50-foI	51-fxI	52-fmI			
TEC	70-I(2000)	71-I	72-I(xxx)			

Table A.4b Qualifying Letters

Letter	Meaning
A	Less than (used only in case of total blanketing)
D	Greater than
E	Less than
I	Interpolated
J	Deduced from x component
M	Mode uncertain
O	Deduced from o component
T	Smoothed from sequence
U	Uncertain
Z	Deduced from z component

Table A.4c Descriptive Letters

Letter	Meaning
A	Blanketing
B	Absorption
C	Non-ionospheric (equipment)
D	Above upper freq. range
E	Below lower freq. range
F	Spread echoes
G	Ionization density too small
H	Stratification
K	Night E layer present
L	Insufficiently defined cusp
M	Mode uncertain
N	Superimposed layers
O	Measurement refers to o component
Q	Range spread
R	Attenuation near critical freq.
S	Interference
T	Interpolated
V	Forked trace
W	Above height range
X	Measurement refers to x component
Y	Lacuna (tilt)
Z	Measurement refers to z component

A.3 OUTPUT FILE DESCRIPTION

The IONOSTAT output filename has the same filename as the input file but with the extension ".OUT" instead of ".INP". It contains a tabular normalized number density (probability density function) for each user-specified parameter with densities also provided for the corresponding qualifying and descriptive letters. These densities are determined for the user specified time interval. The format for these density tables is depicted by Tables A.5a, b, and c for the parameters, qualifying letters, and descriptive letters, respectively. A sample output file called ION1970.OUT is provided with the software package. Note that a 0th bin and an "N+1st" bin of the parameter densities have been added. These bins catch values outside of the user-provided range for each parameter value.

Table A.5a Parameter-Value Density Table

Parameter Value Frequency (MHz) Angle (degrees) Height (km)	Hour Intervals (UT)							
	0-1	1-2	2-3	.	.	.	23-24	NET
ν_0*	*nnn*+	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
ν_1	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
ν_2	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
>	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*

*ν_0 is the zeroth value such that parameter values $\nu \le \nu_0$, ν_1 is the 1st value such that $\nu_0 < \nu \le \nu_1$, ν_2 is the 2st value such that $\nu_1 < \nu \le \nu_2$, and so on, until ν_N is the *N*th value (N parameter bins) such that $\nu_{N\text{-}1} < \nu \le \nu_N$, and finally, ">" correspons to the *N*+1st value (*N* parameter bins) such that $\nu > \nu_N$.
+*nnn* is a probability in the interval 0 < *nnn* ≤ 1

Table A.5b Qualifying-Letter Density Table

Qualifying Letter	Hour Intervals (UT)							
	0-1	1-2	2-3	.	.	.	23-24	NET
A	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
D	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
E	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
Z	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*

Table A.5c Descriptive-Letter Density Table

Descriptive Letter	Hour Intervals (UT)							
	0-1	1-2	2-3	.	.	.	23-24	NET
A	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
B	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
C	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
Z	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*

A.3 IONOSTAT PROGRAM LISTING

```
$FREEFORM
$LARGE
"                    Program IONOSTAT
"
" Purpose:  Process an IONOSONDE data file following the conventions
"           established in UAG-23 and UAG-23A.

" Configuration:  Version 1.00, 3/29/93

" Developed by:  Robert I. Desourdis, Jr.
"                Communications Engineering Laboratory
"                Science Applications International Corporation
"                300 Nickerson Rd., Marlborough, MA 01752
"                Voice:  (508) 460-9500    FAX:  (508) 460-8100

" Developed for:  Naval Undersea Warfare Center
"                 New London Laboratory
"                 New London, CT

    PROGRAM IONOSTAT

" Declare variable types and dimension arrays

" Define a general input record with 120 columns and a holder for the
" previous record

    CHARACTER*120 RECORD

" Define parameters to hold values describing the ionosonde station

    CHARACTER*20 STATION_name, STATION_check
    CHARACTER*5 STATION_code
    CHARACTER*4 TIME_meridian, STATION_COLAT_ddg
    CHARACTER*4 STATION_ELNG_ddg, YEAR
    CHARACTER*2 MONTH
    INTEGER*4 P_code(2), N_file, M_1, M_2, Y_1, Y_2, Y_3, Y_4
    INTEGER*4 YEAR_i, MONTH_i, DAY_i, HOUR_i
    INTEGER*4 YEAR_f, MONTH_f, DAY_f, HOUR_f

" Define 5-character code derived from UAG-23 for hourly interval

    CHARACTER*1 P_char(3), Q_char, D_char

" Define bins for yearly distribution of hourly values
```

```
      REAL*4 HOURLY_Pbins(30,24,100), NET_Pbins(30,100)
      REAL*4 HOURLY_Qbins(30,24,10), NET_Qbins(30,10)
      REAL*4 HOURLY_Dbins(30,24,23), NET_Dbins(30,23), M_hours(30,24)
      REAL*4 N_HOURLY_P(30,24), N_HOURLY_Q(30,24), N_HOURLY_D(30,24)
      REAL*4 N_P(30), N_Q(30), N_D(30), d_P, P_1, P_2, P_3
      REAL*4 P_low(30), P_hgh(30), P_scale(3)
      REAL*4 P_value, P_min, P_max
      REAL*4 P_hours(30), N_hours(30), BLANK_hours(30), MAX_hours(30)
      INTEGER*4 Q_index, D_index, i_FILE, i_CODE, P_index(73)
      INTEGER*4 N_Pbins(30), i_MONTH, PARM_code, P_type(30)

"  Define unused parameters for dual-use input file (IONOSTAT/HFSONE-HFLINKS)

      REAL*4 D_km(10), fMHz_low, fMHz_hgh, hkm_low, hkm_hgh, adg_low, adg_hgh

      INTEGER*4 N_DST, N_FRQ, N_ANG, N_HGT

      LOGICAL*1 MONTHLY_flag, Es_layer_flag

"  Define a character string of BLANK_line for null string searches

      CHARACTER*21 BLANK_line

"  Define list of input files for analysis

      CHARACTER*20 ION_files(25), INP_file, OUT_file, file_INP

"  Define heading variables for output

      CHARACTER*10 P_names(30)
      CHARACTER*5 QUAL_heading, DESC_heading
      CHARACTER*5 P_heading(3), DIM_heading(3)
      CHARACTER*25 HOUR_heading
      CHARACTER*1 QUAL_value(10), DESC_value(23)

"  Define logical variables

      LOGICAL*1 V_flag, CODE_mask(30), F_flag, DIV_flag, Q_flag, D_flag
      LOGICAL*1 YEAR_mask(25), MONTH_mask(12), DAY_mask(31), HOUR_mask(24)

"  Initialize constants

      DATA P_index/1,2,3,4,5,6,4*0,7,8,0,9,10,0,11,3*0,-
               12,0,13,0,14,0,15,3*0,16,17,18,19,20,5*0,-
               21,0,22,23,24,5*0,25,26,27,17*0,28,29,30/

      DATA P_type/3*1,3,2*2,2*1,3,2,2,1,1,2,2,4*1,2,-
```

```
        1,1,3,2,3*1,3*1/

   DATA P_scale/10.0,1.0,100.0/

   DATA BLANK_line/'                    '/

   DATA P_names/'foF2','fxF2','fzF2','M(3000)F2','h"F2','fpF2',-
   'foF1','fxF1','M(3000)F1','h"F1','h"F','foE','foE2','h"E','h"E2',-
   'foEs','fxEs','fbEs','fEs','h"Es','foF1.5','fmin','M(3000)F1.5',-
   'h"f1.5','foI','fxI','fmI','I(2000)','I','I(nnn)'/

   DATA P_heading/' FREQ',' HGHT','     '/
   DATA DIM_heading/'(MHz)',' (km)','FACTR'/
   DATA HOUR_heading/' Universal Time in Hours '/
   DATA QUAL_heading/' QUAL'/
   DATA DESC_heading/' DESC'/

   DATA QUAL_value/'A','D','E','I','J','M','O','T','U','Z'/
   DATA DESC_value/'A','B','C','D','E','F','G','H','K','L',-
        'M','N','O','P','Q','R','S','T','V','W','X','Y','Z'/

" ***********************************************************************
" ***********************************************************************
" Open input file.

   WRITE(6,*) 'Type name of input file without extension ".INP"'
   READ(6,700) file_INP
700 FORMAT(a20)

" Concatenate input and output file names.

   INP_file - file_INP(1:LEN_TRIM(file_INP))//'.INP'
   OUT_file - file_INP(1:LEN_TRIM(file_INP))//'.OUT'

" Read input file.

   OPEN(UNIT-2,STATUS-'OLD',FILE-INP_file)
   READ(2,700) STATION_check
   READ(2,*) HOUR_i, DAY_i, MONTH_i, YEAR_i
   READ(2,*) HOUR_f, DAY_f, MONTH_f, YEAR_f
   READ(2,*) ( YEAR_mask(j), j - 1, 25 )
   READ(2,*) ( MONTH_mask(j), j - 1, 12 )
   READ(2,*) MONTHLY_flag
   READ(2,*) ( DAY_mask(j), j - 1, 31 )
   READ(2,*) ( HOUR_mask(j), j - 1, 24 )
   READ(2,*) N_DST, ( D_km(j), j - 1, N_DST )
   READ(2,*) fMHz_low, fMHz_hgh, N_FRQ, Es_layer_flag
```

```
    READ(2,*) hkm_low, hkm_hgh, N_HGT
    READ(2,*) adg_low, adg_hgh, N_ANG
    DO i - 1, 30
        READ(2,*) j, CODE_mask(j), P_low(j), P_hgh(j), N_Pbins(j)
    END DO
    READ(2,*) DIV_flag

" Read names of standard ionosonde files.  If an error occurs or if
" if no input filenames are present, output the appropriate message
" and stop execution

    i_FILE - 1
100  READ(2,700,ERR-998,END-999) ION_files(i_FILE)

" Determine the number of ionosonde input files

    DO WHILE ( i_FILE .GT. 0 )
      i_FILE - i_FILE + 1
      READ(2,700,END-102) ION_files(i_FILE)
    END DO

102  N_file - i_FILE - 1

" INITIALIZE all bin values to zero

    N_hours - 0.0
    P_hours - 0.0
    BLANK_hours - 0.0
    MAX_hours - 0.0
    NET_Pbins - 0.0
    HOURLY_Pbins - 0.0

    NET_Qbins - 0.0
    HOURLY_Qbins - 0.0

    NET_Dbins - 0.0
    HOURLY_Dbins - 0.0

" ****************************************************************
" START of FILE loop

    DO i_FILE - 1, N_file

" Open input file

        OPEN(UNIT-4,STATUS-'OLD',FILE-ION_files(i_FILE))
```

```
" Start of parameter loop

    i_BLOCK - 0
    DO WHILE ( i_BLOCK .GE. 0 )

" Read the next line of the current input file and check the first
" 21 characters to make sure they are nonblank. If they are blank,
" then a new record should be read.

104     READ(4,702,END-112) RECORD
702     FORMAT(a120)
      IF ( RECORD(1:21) .EQ. BLANK_line ) GO TO 104

" Extract station name, code, standard time meridian, geographic co-latitude,
" east longitude, year, month, and the parameter code

      STATION_name - RECORD(1:20)
      IF ( STATION_name .NE. STATION_check ) GO TO 104
      STATION_code - RECORD(21:26)
        TIME_meridian - RECORD(26:29)
        STATION_COLAT_ddg - RECORD(30:33)
        STATION_ELNG_ddg - RECORD(34:37)
        YEAR - RECORD(38:41)
      Y_1 - ICHAR( RECORD(38:38) ) - 48
      Y_2 - ICHAR( RECORD(39:39) ) - 48
      Y_3 - ICHAR( RECORD(40:40) ) - 48
      Y_4 - ICHAR( RECORD(41:41) ) - 48
      i_YEAR - 1000 * Y_1 + 100 * Y_2 + 10 * Y_3 + Y_4
      IF ( i_YEAR .LT. YEAR_i .OR. i_YEAR .GT. YEAR_f .OR.-
         .NOT. YEAR_mask(i_FILE) ) GO TO 112

        MONTH - RECORD(42:43)
      M_1 - ICHAR( RECORD(42:42) ) - 48
        M_2 - ICHAR( RECORD(43:43) ) - 48
        i_MONTH - 10 * M_1 + M_2

        P_code(1) - ICHAR( RECORD(44:44) ) - 48
        P_code(2) - ICHAR( RECORD(45:45) ) - 48
        PARM_code - 10 * P_code(1) + P_code(2)
        i_CODE - P_index( PARM_code + 1 )

      IF ( ( i_YEAR .EQ. YEAR_i .AND. i_MONTH .LT. MONTH_i ) .OR.-
         ( i_YEAR .EQ. YEAR_f .AND. i_MONTH .GT. MONTH_f ) .OR.-
         .NOT. CODE_mask( i_CODE ) .OR.-
         .NOT. MONTH_mask( i_MONTH ) ) THEN
          DO i - 1, 31
          READ(4,702,END-112) RECORD
```

```
      END DO
      GO TO 110
     END IF

    WRITE(6,*) YEAR, ' ', MONTH, ' CODE: ', RECORD(44:45),-
         ' ', ION_files( i_FILE )

    F_flag - .FALSE.

" Determine the upper and lower bin limits of the parameter for either
" frequency (i_DIM - 1) or height (i_DIM - 2)

    i_DIM - P_type( i_CODE )

" Compute parameter increment value

    d_P - ( P_hgh(i_CODE) - P_low(i_CODE) )-
       / FLOAT( N_Pbins(i_CODE) )

" START loop for each day of the current month

    DO i_DAY - 1, 31

" Read next input record and divide into 24 5-character strings
" Check the first 20 characters to make sure they are nonblank.  If they
" are blank, then a new record should be read.

     READ(4,702,END-997) RECORD
      IF ( RECORD(1:21) .EQ. BLANK_line ) GO TO 110

" Check to see if current day is within interval to be processed

      IF ( ( i_YEAR .EQ. YEAR_i .AND. i_MONTH .EQ. MONTH_i-
         .AND. i_DAY .LT. DAY_i ) .OR.-
         ( i_YEAR .EQ. YEAR_f .AND. i_MONTH .EQ. MONTH_f-
         .AND. i_DAY .GT. DAY_f ) .OR.-
         .NOT. DAY_mask(i_DAY) ) CYCLE

" START loop for each hour of the current day

     DO i_HOUR - 1, 24

      P_value - 0.0

" Check to see if current hour is within interval to be processed

      IF ( ( i_YEAR .EQ. YEAR_i .AND. i_MONTH .EQ. MONTH_i-
```

```
  .AND. i_DAY .EQ. DAY_i .AND. i_HOUR .LT. HOUR_i ) .OR.-
  ( i_YEAR .EQ. YEAR_f .AND. i_MONTH .EQ. MONTH_f-
  .AND. i_DAY .EQ. DAY_f .AND. i_HOUR .GT. HOUR_f ) .OR.-
  .NOT. HOUR_mask(i_HOUR) )-
CYCLE

k_CHAR - 5 * ( i_HOUR - 1 ) + 1

MAX_hours(i_CODE) - MAX_hours(i_CODE) + 1.0
M_hours(i_CODE,i_HOUR) - M_hours(i_CODE,i_HOUR) + 1.0

    IF ( RECORD(k_CHAR:k_CHAR+4) .EQ. '     ' ) THEN
  BLANK_hours(i_CODE) - BLANK_hours(i_CODE) + 1.0
  CYCLE
ELSE IF ( RECORD(k_CHAR:k_CHAR+4) .NE. '    C' ) THEN
  N_hours(i_CODE) - N_hours(i_CODE) + 1.0
    END IF

" Read scaled parameter for the current hour at the ionosonde

P_char(1) - RECORD(k_CHAR:k_CHAR)
    P_char(2) - RECORD(k_CHAR+1:k_CHAR+1)
    P_char(3) - RECORD(k_CHAR+2:k_CHAR+2)
    Q_char - RECORD(k_CHAR+3:k_CHAR+3)
D_char - RECORD(k_CHAR+4:k_CHAR+4)

IF ( P_char(1) .NE. ' ' ) THEN

  P_hours(i_CODE) - P_hours(i_CODE) + 1
      P_1 - REAL( ICHAR( P_char(1) ) - 48 )
      P_2 - REAL( ICHAR( P_char(2) ) - 48 )
      P_3 - REAL( ICHAR( P_char(3) ) - 48 )
      V_flag - .TRUE.

    ELSE IF ( P_char(2) .NE. ' ' ) THEN

     P_hours(i_CODE) - P_hours(i_CODE) + 1
     P_1 - 0.0
           P_2 - REAL( ICHAR( P_char(2) ) - 48 )
           P_3 - REAL( ICHAR( P_char(3) ) - 48 )
           V_flag - .TRUE.

    ELSE IF ( P_char(3) .NE. ' ' ) THEN

     P_hours(i_CODE) - P_hours(i_CODE) + 1
     P_1 - 0.0
           P_2 - 0.0
```

```
            P_3 - REAL( ICHAR( P_char(3) ) - 48 )
            V_flag - .TRUE.

        ELSE

          V_flag - .FALSE.

      END IF

      IF ( V_flag ) THEN

        P_value - ( 100.0*P_1 + 10.0*P_2 + P_3 )-
               / P_scale(i_DIM)

        IF ( P_value .GT. 40.0 .AND. i_DIM .EQ. 1 .AND.-
          i_CODE .EQ. 7 )-
          F_flag - .TRUE.

            DO i_BIN - 1, N_Pbins( i_DIM )

          P_max - P_low(i_CODE) + i_BIN * d_P
          P_min - P_low(i_CODE) + ( i_BIN - 1 ) * d_P

                IF ( P_value .GT. P_min .AND. -
                   P_value .LE. P_max ) THEN
                  HOURLY_Pbins(i_CODE,i_HOUR,i_BIN) - -
                    HOURLY_Pbins(i_CODE,i_HOUR,i_BIN) + 1.0
                  NET_Pbins(i_CODE,i_BIN) - -
                    NET_Pbins(i_CODE,i_BIN) + 1.0
                  GO TO 107
                END IF

            END DO

107         N_HOURLY_P(i_CODE,i_HOUR) - -
                 N_HOURLY_P(i_CODE,i_HOUR) + 1.0
            N_P(i_CODE) - N_P(i_CODE) + 1.0

        END IF

      Q_flag - .FALSE.

      IF ( Q_char .NE. ' ' ) THEN

        Q_index - 0
        i_BIN - 1
```

```
      DO WHILE ( Q_index .EQ. 0 .AND. i_BIN .LE. 10 .AND. -
             .NOT. Q_flag )

        IF ( Q_char .EQ. QUAL_value(i_BIN) ) THEN
          Q_index - i_BIN
          Q_flag - .TRUE.
        END IF

        i_BIN - i_BIN + 1

      END DO

      IF ( Q_flag ) THEN

        HOURLY_Qbins(i_CODE,i_HOUR,Q_index) - -
          HOURLY_Qbins(i_CODE,i_HOUR,Q_index) + 1.0
        NET_Qbins(i_CODE,i_BIN) - -
          NET_Qbins(i_CODE,i_BIN) + 1.0
        N_HOURLY_Q(i_CODE,i_HOUR) - -
           N_HOURLY_Q(i_CODE,i_HOUR) + 1.0
        N_Q(i_CODE) - N_Q(i_CODE) + 1.0

      END IF

    END IF

    D_flag - .FALSE.

         IF ( D_char .NE. ' ' ) THEN

           D_index - 0
      i_BIN - 1

      DO WHILE ( D_index .EQ. 0 .AND. i_BIN .LE. 23 .AND. -
              .NOT. D_flag )

        IF ( D_char .EQ. DESC_value(i_BIN) ) THEN
          D_index - i_BIN
          D_flag - .TRUE.
        END IF

        i_BIN - i_BIN + 1

      END DO

      IF ( D_flag ) THEN
```

```
                HOURLY_Dbins(i_CODE,i_HOUR,D_index) - -
                  HOURLY_Dbins(i_CODE,i_HOUR,D_index) + 1.0
                NET_Dbins(i_CODE,i_BIN) - -
                  NET_Dbins(i_CODE,i_BIN) + 1.0
                N_HOURLY_D(i_CODE,i_HOUR) - -
                  N_HOURLY_D(i_CODE,i_HOUR) + 1.0
                N_D(i_CODE) - N_D(i_CODE) + 1.0

              END IF

            END IF

" End of hourly loop for current day, parameter, and file (year)

          END DO

" End of daily loop for current parameter and file (year)

        END DO

110       i_BLOCK - i_BLOCK + 1

        IF ( F_flag ) THEN
          WRITE(6,711) '*'
711         FORMAT('+',a1)
        END IF

        IF ( i_MONTH .LT. MONTH_f ) THEN
          CYCLE
        ELSE
          GO TO 112
        END IF

      END DO

" All input records in the current input file have been read.  Proceed
" to next input file

112     CLOSE(UNIT-4)

" Consider next input file (consider next year)

    END DO

" All input files have been read.  Normalize each distribution count
" by the numbers of samples
```

```
DO i_CODE - 1, 30

    IF ( .NOT. CODE_mask( i_CODE ) ) CYCLE

    i_DIM - P_type( i_CODE )

    DO i_BIN - 1, N_Pbins( i_DIM )

      IF ( DIV_flag ) THEN

        DO i_HOUR - 1, 24

            IF ( N_HOURLY_P(i_CODE,i_HOUR) .NE. 0.0 ) THEN
              HOURLY_Pbins(i_CODE,i_HOUR,i_BIN) - -
                          HOURLY_Pbins(i_CODE,i_HOUR,i_BIN) -
                          / N_HOURLY_P(i_CODE,i_HOUR)
            END IF

        END DO

        IF ( N_P(i_CODE) .NE. 0.0 ) THEN
            NET_Pbins(i_CODE,i_BIN) - NET_Pbins(i_CODE,i_BIN) -
                                  / N_P(i_CODE)
        END IF

      ELSE

        DO i_HOUR - 1, 24

            IF ( N_hours(i_CODE) .NE. 0.0 ) THEN
              HOURLY_Pbins(i_CODE,i_HOUR,i_BIN) - -
                          HOURLY_Pbins(i_CODE,i_HOUR,i_BIN) -
                  / M_hours(i_CODE,i_HOUR)
            END IF

        END DO

        IF ( N_hours(i_CODE) .NE. 0.0 ) THEN
            NET_Pbins(i_CODE,i_BIN) - NET_Pbins(i_CODE,i_BIN) -
                      / MAX_hours(i_CODE)
        END IF

      END IF

    END DO

    DO i_BIN - 1, 10
```

```
IF ( DIV_flag ) THEN

  DO i_HOUR - 1, 24

      IF ( N_HOURLY_Q(i_CODE,i_HOUR) .NE. 0.0 ) THEN
        HOURLY_Qbins(i_CODE,i_HOUR,i_BIN) - -
                        HOURLY_Qbins(i_CODE,i_HOUR,i_BIN) -
                        / N_HOURLY_Q(i_CODE,i_HOUR)
      END IF

  END DO

  IF ( N_Q(i_CODE) .NE. 0.0 ) THEN
      NET_Qbins(i_CODE,i_BIN) - NET_Qbins(i_CODE,i_BIN)-
                        / N_Q(i_CODE)
  END IF

ELSE

  DO i_HOUR - 1, 24

      IF ( N_HOURLY_Q(i_CODE,i_HOUR) .NE. 0.0 ) THEN
        HOURLY_Qbins(i_CODE,i_HOUR,i_BIN) - -
                        HOURLY_Qbins(i_CODE,i_HOUR,i_BIN) -
              / M_hours(i_CODE,i_HOUR)
      END IF

  END DO

  IF ( N_Q(i_CODE) .NE. 0.0 ) THEN
      NET_Qbins(i_CODE,i_BIN) - NET_Qbins(i_CODE,i_BIN)-
              / MAX_hours(i_CODE)
  END IF

END IF

END DO

DO i_BIN - 1, 23

  IF ( DIV_flag ) THEN

    DO i_HOUR - 1, 24

        IF ( N_HOURLY_D(i_CODE,i_HOUR) .NE. 0.0 ) THEN
          HOURLY_Dbins(i_CODE,i_HOUR,i_BIN) - -
```

```
                                HOURLY_Dbins(i_CODE,i_HOUR,i_BIN) -
                                / N_HOURLY_D(i_CODE,i_HOUR)
           END IF

        END DO

        IF ( N_D(i_CODE) .NE. 0.0 ) THEN
           NET_Dbins(i_CODE,i_BIN) - NET_Dbins(i_CODE,i_BIN)-
                                    / N_D(i_CODE)
        END IF

      ELSE

        DO i_HOUR - 1, 24

           IF ( N_HOURLY_D(i_CODE,i_HOUR) .NE. 0.0 ) THEN
             HOURLY_Dbins(i_CODE,i_HOUR,i_BIN) - -
                                HOURLY_Dbins(i_CODE,i_HOUR,i_BIN) -
                 / M_hours(i_CODE,i_HOUR)
           END IF

        END DO

        IF ( N_D(i_CODE) .NE. 0.0 ) THEN
           NET_Dbins(i_CODE,i_BIN) - NET_Dbins(i_CODE,i_BIN)-
                                    / MAX_hours(i_CODE)
        END IF

      END IF

    END DO

  END DO

" Output the probability distributions for each parameter code, both
" for each hour and over all hours in a column format

  OPEN(UNIT-3,STATUS-'UNKNOWN',ACCESS-'APPEND',FILE-OUT_file)

  WRITE(3,704) STATION_name
704 FORMAT(/////25x,'IONOSONDE PARAMETER STATISTICS AT ', a20)

  WRITE(3,705) HOUR_i, DAY_i, MONTH_i, YEAR_i, HOUR_f, DAY_f,-
        MONTH_f, YEAR_f
705 FORMAT(///10x,'IONOSONDE measurements processed for the period: ',-
      3(i2,', '),i4,' to ',3(i2,', '),i4)
```

```
   WRITE(3,706) (CODE_mask(i),i-1,30)
706  FORMAT(//10x,'Parameter code mask:  ',30(l1,1x))

   DO i_CODE - 1, 30

     IF ( .NOT. CODE_mask( i_CODE ) -
        .OR. MAX_hours(i_CODE) .EQ. 0.0 ) CYCLE

     d_P - ( P_hgh(i_CODE) - P_low(i_CODE) )-
        / FLOAT( N_Pbins(i_CODE) )

     i_DIM - P_type( i_CODE )

     WRITE(3,708) P_names( i_CODE )
708    FORMAT('1',20x,'***** Statistical results for parameter:  ',-
         a10,' *****')

     IF ( i_DIM .EQ. 1 ) THEN
       WRITE(3,731) INT(P_low(i_CODE)), INT(P_hgh(i_CODE)),-
              N_Pbins(i_CODE)
731      FORMAT(//1x,'Minimum frequency:  ',i4,' MHz'-
              '  Maximum frequency:  ',i4,' MHz'-
          '  Number of bins:  ',i3)
     ELSE IF ( i_DIM .EQ. 2 ) THEN
       WRITE(3,732) INT(P_low(i_CODE)), INT(P_hgh(i_CODE)),-
              N_Pbins(i_CODE)
732      FORMAT(//1x,'Minimum height:  ',i4,' km '-
          '  Maximum height:  ',i4,' km '-
          '  Number of bins:  ',i3)
     ELSE
       WRITE(3,733) P_low(i_CODE), P_hgh(i_CODE),-
              N_Pbins(i_CODE)
733      FORMAT(//1x,'Minimum factor:  ',f5.2,-
          '  Maximum factor:  ',f5.2,-
          '  Number of bins:  ',i3)
     END IF

     IF ( N_hours(i_CODE) .NE. 0.0 ) THEN
       P_hours_pct - 100 * P_hours( i_CODE ) / N_hours(i_CODE)
     END IF

     B_hours_pct - 100 * BLANK_hours( i_CODE ) / MAX_hours(i_CODE)
     X_hours_pct - 100 * P_hours( i_CODE ) / MAX_hours(i_CODE)

     WRITE(3,710) P_names( i_CODE ), INT( MAX_hours(i_CODE) ),-
           INT( N_hours(i_CODE) ), INT( P_hours( i_CODE ) ),-
           INT( X_hours_pct ), INT( P_hours_pct ),-
```

```
        INT( BLANK_hours(i_CODE) ), INT( B_hours_pct )
710   FORMAT(//20x,'IONOSONDE PARAMETER:  ', a10-
     //'                          Total number of hours:  ',i6-
     /'                      Number of nonblank hours:  ',i6-
     /' Number of nonblank hours with parameter values:  ',i6-
     /'       % of total hours with a parameter value:  ',i3-
     /'     % of nonblank hours with parameter values:  ',i3-
     /'                   Number of blank-entry hours:  ',i6-
     /'             % of total hours with blank entry:  ',i3)

      IF ( DIV_flag ) THEN
        WRITE(3,722)
722       FORMAT(//' Probabilities conditioned on usable hours')
      ELSE
        WRITE(3,724)
724       FORMAT(//' Probabilities determined over all hours')
      END IF

      WRITE(3,712) P_heading( i_DIM ), HOUR_heading
712     FORMAT(//4x,a5,20x,a25)
      WRITE(3,714) DIM_heading( i_DIM ), (i,i-1,24)
714     FORMAT(4x,a5,24(i3,2x),'NET')

      DO i_BIN - 1, N_Pbins( i_CODE )

        P_value - P_low(i_CODE) + i_BIN * d_P

        WRITE(3,716) P_value,-
            (HOURLY_Pbins(i_CODE,i_HOUR,i_BIN),i_HOUR-1,24),-
            NET_Pbins(i_CODE,i_BIN)
716       FORMAT(1x,f6.2,25f5.2)

        END DO

      WRITE(3,718) HOUR_heading
718     FORMAT(///26x,a25)
      WRITE(3,714) QUAL_heading, (i,i-1,24)

        DO i_BIN - 1, 10

        WRITE(3,720) QUAL_value(i_BIN),-
            (HOURLY_Qbins(i_CODE,i_HOUR,i_BIN),i_HOUR-1,24),-
            NET_Qbins(i_CODE,i_BIN)
720       FORMAT(6x,a1,25f5.2)

        END DO
```

```
      WRITE(3,718) HOUR_heading
      WRITE(3,714) DESC_heading, (i,i-1,24)

        DO i_BIN - 1, 23

        WRITE(3,720) DESC_value(i_BIN),-
            (HOURLY_Dbins(i_CODE,i_HOUR,i_BIN),i_HOUR -1,24),-
            NET_Dbins(i_CODE,i_BIN)

        END DO

    END DO

    CLOSE(UNIT-2)

    STOP

997  WRITE(6,*) 'Error on input, probably wrong number of -
               characters in record'
    CLOSE(UNIT-2)
    CLOSE(UNIT-3)
    STOP

998  WRITE(6,*) 'Error on input, probably no access to input file'
    CLOSE(UNIT-2)
    CLOSE(UNIT-3)
    STOP

999  WRITE(6,*) 'No ionosonde input files were listed'
    CLOSE(UNIT-2)
    CLOSE(UNIT-3)
    STOP

    END
```

APPENDIX B IONOLINK COMPUTER PROGRAM

B.1 DESCRIPTION AND INSTALLATION

IONOLINK is a Microsoft FORTRAN 5.0 computer program developed and executed on a Gateway 2000 486/33-MHz PC. The program was written and debugged using the Power Workbench (PWB) development tool from Microsoft (MS) which is available with its FORTRAN product. MS-FORTRAN 5.0 employs ANSI FORTRAN 77 as well as several additional features for compatibility with VAX FORTRAN available from the Digital Equipment Corporation. The purpose of the IONOLINK program is to accumulate numerical densities for oblique standard MUF (maximum usable frequency) values using input files in the "NEW URSI" data format as published in International Council of Scientific Unions Panel on World Data Centers "GUIDE to the WORLD DATA CENTER SYSTEM", Part 2. These parameters include hourly junction frequencies (JFs), "standard" maximum usable frequency (MUF) multipliers, and ionospheric reflection heights (virtual heights), for the each of the observed ionosperhic layers.

IONOLINK consists of a two source code modules, IONOLINK.FOR and HFLINK.FOR which are compiled and linked by the PWB tool using the "make" file called HF.MAK into IONOLINK.EXE. Proper use of the MB-PWB tool is beyond the scope of this appendix. The executable image is invoked at the user prompt from drive C by the command:

C>**<u>IONOLINK</u>**

where the highlighted and underlined text indicates user entry. The "C>" in this example is displayed by the PC. The program then asks the user for the name of the desired IONOLINK input file with the following prompt:

Type name of input file without extension ".INP"

The user then types the name of the input file without the trailing (.) or file extension. The IONOLINK program *assumes* that the input file extension is ".INP". For example, if the user's input file is called ION1970.INP and it resides in directory "INPUT" on drive "D", then the user would respond to the prompt with

<u>D:\INPUT\ION1970</u>

and the IONOLINK program would automatically read file ION1970.INP in the indicated directory.

B.2 INPUT FILE DESCRIPTION

B.2.1 IONOLINK Input File

The user-input file must be created using a standard ASCII editor. IONOLINK reads this input file in a format-free format, so exactly one comma (,) or one or more spaces may be used to delimit entries. For example, consider the following example input file:

SCOTT BASE
1, 1, 1, 1
24, 31, 14, 2000
T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T
T, T, T, T, T, T, T, T, T, T, T, T
T
T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T
T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T, T
10, 20.0, 50.0, 100.0, 200.0, 400.0, 600.0, 800.0, 1000.0, 1500.0, 2000.0
2.0, 30.0, 56, T
0.0, 600.0, 60
0.0, 90.0, 60
1, T, 0.0, 12.0, 60
2, F, 0.0, 30.0, 60
3, F, 0.0, 30.0, 60
4, T, 2.0, 4.0, 50
5, F, 0.0, 600.0, 60
6, F, 0.0, 600.0, 60
7, T, 0.0, 60.0, 60
8, F, 0.0, 30.0, 60
9, F, 0.0, 10.0, 50
10, F, 0.0, 600.0, 60
11, T, 150.0, 600.0, 45
12, T, 0.0, 5.0, 25
13, F, 1.0, 30.0, 60
14, T, 90.0, 150.0, 60
15, F, 0.0, 600.0, 60
16, T, 0.0, 10.0, 50
17, F, 1.0, 30.0, 60
18, T, 0.0, 5.0, 25
19, F, 1.0, 30.0, 60
20, T, 90.0, 190.0, 20
21, F, 1.0, 30.0, 60
22, T, 0.0, 5.0, 25
23, F, 0.0, 10.0, 50
24, F, 0.0, 600.0, 60
25, F, 1.0, 30.0, 60
26, T, 0.0, 16.0, 40

27, F, 1.0, 30.0, 60 39
28, F, 1.0, 30.0, 60 40
29, F, 1.0, 30.0, 60 41
30, F, 1.0, 30.0, 60 42
T 43
D:\NUWCION\67Q70.NEW 44
D:\NUWCION\67Q71.NEW 45
D:\NUWCION\67Q72.NEW 46
. .
. .
. .
D:\NUWCION\67Q??.NEW 68

Each record (line) is shown numbered to the right of the input values to provide an index for reference to each item in this description. These numbers must *not* appear in the user-input file or an input error will occur. A description of each input value referenced by these numbers is provided in Table A-1.

B.2.2 Ionosonde Data File Format

The "NEW URSI" data format as published in International Council of Scientific Unions Panel on World Data Centers "GUIDE to the WORLD DATA CENTER SYSTEM", part 2, defines the format of the ionosonde data input files. Although this format includes hourly median, upper/lower quartile, and upper/lower decile values derived for each parameter, none of these entries were provided in the data files provided as GFI for this study. The program should be capable of reading these values without failure, although it does not provide these values in its output.

Data for each parameter during one month form a physical block of fixed length 4800 bytes, which comprise 40 records each of length 120 bytes. The first record identifies the station, month of observation, and the parameter recorded. Subsequent records contain the actual data in the form of 24 groups of 5 characters representing values for the 24 hours of the day. Each 5 character group is coded using the rules laid down in UAG-23. Data for a year form a file within which the order of the blocks must follow time order. The order of the parameters within the file is not significant. The format of each physical block is provided in Table B.2.

Note that definitions for parameters I and I(xxx), records 41 and 42, respectively, were not found in UAG-23. These values were not required for the analysis performed on HF links in study for which IONOLINK was developed.

Table B.1 Input Variable Descriptions for IONOLINK Program

INPUT FILE ROW NUMBER	ITEM NUMBER IN ROW	FORTRAN VARIABLE TYPE	DESCRIPTION	TYPICAL VALUES
1	1	CHARACTER*20	Name of Ionosonde station used to find the start of each month's data records	SCOTT BASE
2	1	INTEGER*4	First hour in time interval for bin-accumulation	1
"	2	"	First day in time interval for bin accumulation	1
"	3	"	First month in time interval for bin accumulation	1
"	4	"	First year in time interval for bin-accumulation	1970
3	1	INTEGER*4	Last hour in time interval for bin-accumulation	24
"	2	"	Last day in time interval for bin accumulation	31
"	3	"	Last month in time interval for bin accumulation	12
"	4	"	Last year in time interval for bin-accumulation	1972
4	1-25	LOGICAL*1	Use/ignore MASK for up to 25 years of ionosonde data files, one file per year, e.g., 1970 - 1972	T or F for each entry
5	1-12	LOGICAL*1	Use/ignore MASK for up to 12 months of ionosonde data for each year (file), 1 through 12	T or F for each entry
6	1	LOGICAL*1	Logic switch for program IONOLINK, not used in program IONOLINK: T creates hourly FOT, MUF (standard), and HPF statistics for oblique HF links, F creates same density tabulations	T or F ignored
7	1-31	LOGICAL*1	Use/ignore MASK for up to 31 days of ionosonde data for each month (1 through 31)	T or F for each entry
8	1-24	LOGICAL*1	Use/ignore MASK for up to 24 hours of ionosonde data for each day (1 through 24)	T or F for each entry

Table B.1 Input Variable Descriptions for IONOLINK Program (Continued)

INPUT FILE ROW NUMBER	ITEM NUMBER IN ROW	FORTRAN VARIABLE TYPE	DESCRIPTION	VALUES
9	1	INTEGER*4	Number of oblique path lengths for IONOLINK (10 MAX)	10
9	2-11	REAL*4	Oblique path lengths (km) for IONOLINK, *not* used in program IONOLINK (10 values MAX)	0.0 to 4000.0
10	1	REAL*4	Lower frequency limit (MHz) for IONOLINK-computed FOT, MUF, & HPF values	2.0
"	2	REAL*4	Upper frequency limit (MHz) for IONOLINK-computed FOT, MUF, & HPF values	60.0
"	3	INTEGER*4	Number of frequency bins for IONOLINK-computed FOT, MUF, & HPF values (60 MAX)	56
"	4	LOGICAL*1	Logical switch to turn off sporadic E layer in IONOLINK analysis	T or F
11	1	REAL*4	Lower height limit (km) for IONOLINK-computed FOT, MUF, & HPF values	0.0
"	2	REAL*4	Upper height limit (MHz) for IONOLINK-computed FOT, MUF, & HPF values	600.0
"	3	INTEGER*4	Number of height bins for IONOLINK-computed FOT, MUF, & HPF values (60 MAX)	60

Table B.1 Input Variable Descriptions for IONOLINK Program (Continued)

INPUT FILE ROW NUMBER	ITEM NUMBER IN ROW	FORTRAN VARIABLE TYPE	DESCRIPTION	VALUES
12	1	REAL*4	Lower antenna elevation angle limit (deg) for IONOLINK-computed FOT, MUF, & HPF values	0.0
"	2	REAL*4	Upper antenna elevation angle limit (deg) for IONOLINK-computed FOT, MUF, & HPF values	90.0
"	3	INTEGER*4	Number of angle bins for IONOLINK-computed FOT, MUF, & HPF values (60 MAX)	60
13, 14, 15, 19, 20, 24, 25, 28, 29, 30, 31, 33, 34, 37, 38, 39	1	LOGICAL*1	Logical switch to turn on analysis for the corresponding ionosonde-scaled-frequency parameter codes described in Section B.2.2. A "T" tells the IONOLINK program to process the parameter, not processed if "F".	T or F
"	2	REAL*4	Minimum value of frequency to be used in density accumulation bins	2.0
"	3	REAL*4	Maximum value of frequency to be used in density accumulation bins	30.0
"	4	INTEGER*4	Number of frequency bins to be used in density accumulation bins	28
16, 21, 35, 40	1	LOGICAL*1	Logical switch to turn on analysis for the corresponding ionosonde-scaled-factor parameter codes described in Section B.2.2. A "T" tells the IONOLINK program to process the parameter, not processed if "F".	T or F
"	2	REAL*4	Minimum value of factor to be used in density accumulation bins	2.0
"	3	REAL*4	Maximum value of factor to be used in density accumulation bins	4.0
"	4	INTEGER*4	Number of factor bins to be used in density accumulation bins	20

Table B.1 Input Variable Descriptions for IONOLINK Program (Continued)

INPUT FILE ROW NUMBER	ITEM NUMBER IN ROW	FORTRAN VARIABLE TYPE	DESCRIPTION	VALUES
17, 18, 22, 23, 26, 27, 32, 36	1	LOGICAL*1	Logical switch to turn on analysis for the corresponding ionosonde-scaled-height parameter codes described in Section B.2.2. A "T" tells the IONOLINK program to process the parameter, not processed if "F".	**T** or **F**
"	2	REAL*4	Minimum value of height to be used in density accumulation bins	**0.0**
"	3	REAL*4	Maximum value of height to be used in density accumulation bins	**600.0**
"	4	INTEGER*4	Number of height bins to be used in density accumulation bins	**60**
41, 42	1	LOGICAL*1	Logical switch to turn on analysis for the corresponding ionosonde-scaled parameter code as described in Section B.2.2. A "T" tells the IONOLINK program to process the parameter, not processed if "F".	**T** or **F**
"	2	REAL*4	Minimum value of parameter to be used in density accumulation bins	**0.0** (?)
"	3	REAL*4	Maximum value of parameter to be used in density accumulation bins	**600.0** (?)
"	4	INTEGER*4	Number of parameter bins to be used in density accumulation bins	**60** (?)
43	1	LOGICAL*1	Logical switch to have densities on total elapsed time or elapsed time for which ionosonde data was possible, i.e., no equipment failure (qualifying letter "C")	**T** or **F**
44-68	1	CHARACTER*20	Ionosonde data filenames, including drive and subdirectory, if not the same as IONOLINK.EXE, up to 25 filenames may be provided	See Section B.2.1 for examples

Table B.2 Ionosonde (New URSI) Data Format

Record	Columns	Description
1	1-20	Station name
1	21-25	Station code
1	26-29	Standard time meridian of the station (e.g. 150W, 90E, etc., with 000W or 000E = UT)
1	30- 33	Geographic co-latitude in tenths of a degree
1	34- 37	Geographic East longitude in tenths of a degree
1	38- 41	Year
1	42- 43	Month
1	44- 45	Parameter code (See UAG-23 characteristic code)
1	46-120	Spare
2	24 X 5-character code	Hourly data for the first day of the month (i.e. foF2 values - 078 R, 080 , etc.)
3	24 X 5-character code	Hourly data for the second day of the month (i.e. foF2 values - 078 R, 080 , etc.)
.	24 X 5-character code	.
.	24 X 5-character code	.
.	24 X 5-character code	.
32	24 X 5-character code *(if available)*	Hourly data for the thirty-first day of the month (If less than 31 days, blank fill.)
33		Medians
34		Median Count
35		Upper Quartile
36		Lower Quartile
37		Upper Decile
38		Range
39		Lower Decile
40		Spare

Not all of the 5-character scaled-parameter values were reported for each hour of the 15 years of Scott Base ionosonde data provided for the study. In this case, blank fill was used as a place holder. Note that the 15 files provided for this study were 67Q58.NEW, 67Q70.NEW, 67Q71.NEW, ..., 67Q83.NEW. None of these files included rows 33-40 in the monthly data blocks for each parameter. The IONOLINK program should be able to read these values if present without disturbing normal execution. If N parameters have been scaled, then there will be N blocks for each of the months contained within a single file. For the standard" N = 14 parameters, the ionosonde data file should be organized as shown in Table B.3. A complete description of the parameter codes, descriptive, and qualification letters summarized in Table B.4a, b, and c, respectively, can be found in UAG-23 [].

Table B.3 Ionosonde Data File Organization

Block	Month	Parameter (Characteristic)	Numeric code
1	January	foF2	00
2	January	M(3000)F2	03
.	.	.	.
.	.	.	.
.	.	.	.
13	January	fxI	51
14	January	fmI	52
15	February	foF2	00
16	February	M(3000)F2	03
.	.	.	.
.	.	.	.
.	.	.	.
167	December	fxI	51
168	December	fmI	52

Table B.4a Parameter Codes

Description	Parameter Codes and Meaning				
F2 layer	00-foF2	01-fxF2	02-fzF2	03-M(3000)F2	04-h'F2	05-hpF2
F1 layer	10-foF1	11-fxF1	13-M(3000)F1	14-h'F1	16-h'F	
E layer	20-foE	22-foE2	24-h'E	26-h'E2		
Es layer	30-foEs	31-fxEs	32-fbEs	33-fEs	34-h'Es	
Other	40-foF1.5	42-fmin	43-m(3000)F1.5	44-h'F1.5		
Spread	50-foI	51-fxI	52-fmI			
TEC	70-I(2000)	71-I	72-I(xxx)			

Table B.4b Qualifying Letters

Letter	Meaning
A	Less than (used only in case of total blanketing)
D	Greater than
E	Less than
I	Interpolated
J	Deduced from x component
M	Mode uncertain
O	Deduced from o component
T	Smoothed from sequence
U	Uncertain
Z	Deduced from z component

Table B.4c Descriptive Letters

Letter	Meaning
A	Blanketing
B	Absorption
C	Non-ionospheric (equipment)
D	Above upper freq. range
E	Below lower freq. range
F	Spread echoes
G	Ionization density too small
H	Stratification
K	Night E layer present
L	Insufficiently defined cusp
M	Mode uncertain
N	Superimposed layers
O	Measurement refers to o component
Q	Range spread
R	Attenuation near critical freq.
S	Interference
T	Interpolated
V	Forked trace
W	Above height range
X	Measurement refers to x component
Y	Lacuna (tilt)
Z	Measurement refers to z component

B.3 OUTPUT FILE DESCRIPTION

The IONOLINK computer program can generate two different output file formats depending on the value of input file record number six (6). If false, the IONOLINK output filename has the same filename as the input file but with the extension ".OUT" instead of ".INP". It contains a tabular normalized number density (probability density function) for the dominant propagation mode (currently, 1F2, 1F1, 1E, 2E, 1Es, and 2Es), standard MUF values, antenna elevation angles, and virtual reflection heights determined for each user-specified link range. These densities are determined for the user specified time interval. The format for these density tables is depicted in Tables B.5a, b, and c. A sample output file called ION1970L.OUT is provided with the software package.

The second output file format was developed to provide a direct output for comparison with IONCAP, ASAPS, or other HF prediction code output. This output file provides the optimum working frequency (OWF or FOT, 10% not exceeded), the median standard MUF value (50% not exceeded), and the lower decile standard MUF value (90% not exceeded) versus hour of day and link range. In addition, the corresponding average antenna take-off angle for each standard MUF-distribution value is also provided. This output file has the extension ".LNK" and cannot be created simultaneously with the corresponding ".OUT" file. Parameter six (6) in the input file determines the form of IONOLINK output. The format of this file is outlined in Table 6 and a sample "*.LNK" file is provided with the software.

Table B.5a Propagation Mode Density Table

	Hour Intervals (UT)							
Propagation Mode	0-1	1-2	2-3	.	.	.	23-24	NET
1F2	*nnn**	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
1F1	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
1E	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
2E	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
1Es	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
2Es	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*

**nnn* is a probability ($0 \le nnn \le 1$)

Table B.5b Standard-MUF Density Table

	Hour Intervals (UT)							
Frequency (MHz)	0-1	1-2	2-3	.	.	.	23-24	NET
f_1-f_2*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
f_2-f_3	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
f_3-f_4	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
f_{N-1}-f_N	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*

*f_i - f_{i+1} implies that the standard MUF value f is within the interval $f_{i-1} < f \le f_i$ with the indicated probability.

Table B.5c Height- and Angle-Value Density Table

	Hour Intervals (UT)							
Angle (degrees), Height (km)	0-1	1-2	2-3	.	.	.	23-24	NET
v_0*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
v_1	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
v_2	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
.	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*
>	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*	*nnn*

*v_0 is the zeroth value such that height/angle values $v \le v_0$, v_1 is the 1st value such that $v_0 < v \le v_1$, v_2 is the 2st value such that $v_1 < v \le v_2$, and so on, until v_N is the *N*th value (*N* height/angle bins) such that $v_{N-1} < v \le v_N$, and finally, ">" corresponds to the *N*+1st value (*N* height/angle bins) such that $v > v_N$.

Table B.6 FOT, MUF, HPF Table in "*.LNK" Output File

	Hour Intervals (UT)							
Range r (km)	0-1	1-2	2-3	.	.	.	23-24	NET
r_1	*fff**	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*
	aaa+	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*
r_1	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*
	aaa+	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*
r_2	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*
.	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*
	aaa+	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*
.	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*
	aaa+	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*
.	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*
	aaa+	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*
r_N	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*	*fff*
	aaa+	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*	*aaa*

**fff* - frequency in MHz +*aaa* - angle in degrees

B.3 IONOLINK PROGRAM LISTING

B.3.1 IONOLINK.FOR Source Program

```
$FREEFORM
$LARGE

    INTERFACE TO SUBROUTINE HFLINKS( i1, i2, l1, l2, l3 )
    INTEGER*4 i1, i2
    LOGICAL*1 l1(10), l2, l3
    END

    INTERFACE TO SUBROUTINE PARMBIN( i1, i2, i3, r1, c1, c2 )
    REAL*4 r1
    INTEGER*4 i1, i2, i3
    CHARACTER*1 c1, c2
    END

"                     Program HFSONDE
"
" Purpose:      Process an IONOSONDE data file following the conventions
"               established in UAG-23 and UAG-23A and determine the optimum
"               frequencies for an HF communications link with its midpath
"               above the ionosonde. The allowable modes included in this
"               version of the software are 1F2, 1F1, 1E, 1Es, 2E, & 2Es.
"               Additional modes will be added at a future date.

    PROGRAM HFSONDE

" Declare variable types and dimension arrays

" Define a general input record with 120 columns and a holder for the
" previous record

    CHARACTER*120 RECORD_I, RECORD

" Define parameters to hold values describing the ionosonde station

    CHARACTER*20 STATION_name, STATION_check
    CHARACTER*5 STATION_code
    CHARACTER*4 TIME_meridian, STATION_COLAT_ddg
    CHARACTER*4 STATION_ELNG_ddg, YEAR
    CHARACTER*2 MONTH, OLD_MONTH
    CHARACTER*6 f_RANGE(12)
    INTEGER*4 P_code(2), N_file, M_1, M_2, Y_1, Y_2, Y_3, Y_4
    INTEGER*4 YEAR_i, MONTH_i, DAY_i, HOUR_i
    INTEGER*4 YEAR_f, MONTH_f, DAY_f, HOUR_f
```

```
" Define 5-character code derived from UAG-23 for hourly interval

    CHARACTER*1 P_char(3), Q_char, D_char

" Define bins for yearly distribution of hourly values

    REAL*4 d_P, P_1, P_2, P_3, P_value, MAX_hours(1:30,1:24)
    REAL*4 P_low(1:30), P_hgh(1:30), P_scale(1:3)

    REAL*4 fMHz_low, fMHz_hgh, adg_low, adg_hgh, hkm_low, hkm_hgh

    INTEGER*4 i_FILE, i_CODE, P_index(1:73), N_DISP
    INTEGER*4 N_Pbins(1:30), i_MONTH, PARM_code, P_type(1:30)

" Declare arrays for HF link calculations

    REAL*4 fMHz_km_hr_bin, adg_km_hr_bin, hkm_km_hr_bin
    REAL*4 f_limit, f_hr_bin, f_bin
    REAL*4 N_km_hr_F2, N_km_hr_F1, N_km_hr_1E, N_km_hr_1Es, N_km_hr_2E
    REAL*4 N_km_hr_2Es, fMHz_km_bin, adg_km_bin, hkm_km_bin
    REAL*4 N_km_F2, N_km_F1, N_km_1E, N_km_1Es, N_km_2E, N_km_2Es
    REAL*4 ANG_km_hr_frq, m_MUF, b_MUF, DUM_1, DUM_2, N_km_hr, N_km
    REAL*4 N_km_hr_cutE, N_km_hr_cutEs, N_km_cutE, N_km_cutEs
    REAL*4 d_f, d_a, d_h

    INTEGER*4 i_DAY, i_HOUR, i_DST
    INTEGER*4 N_DST, N_FRQ, N_bins, N_HGT, N_ANG, month_OLD

    CHARACTER*5 L_heading(3)
    CHARACTER*25 DIST_heading

" Define storage for each parameter code, descriptive, and qualifying
" letter.

    REAL*4 foF2, fxF2, fzF2, M3000F2, hF2, hpf2, foF1, fxF1,-
           M3000F1, hF1, hF, foE, foE2, hE, hE2, foEs,-
           fxEs, fbEs, fEs, hEs, foF1d5, fmin, M3000F1d5, hf1d5,-
           foI, fxI, fmI, I2000, II, Ixxx

" Define unused logical parameter employed in the IONSTATS program

    LOGICAL*1 DIV_flag

" Define a character string of BLANK_line for null string searches

    CHARACTER*21 BLANK_line
```

```
" Define list of input files for analysis

    CHARACTER*20 ION_files(1:25), INP_file, OUT_file, file_INP
    CHARACTER*20 LNK_file

" Define heading variables for output

    CHARACTER*10 P_names(1:30)
    CHARACTER*5 QUAL_heading, DESC_heading
    CHARACTER*5 P_heading(1:3), DIM_heading(1:4)
    CHARACTER*25 HOUR_heading
    CHARACTER*1 QUAL_value(1:10), DESC_value(1:23)

    LOGICAL*1 YEAR_mask(1:25), MONTH_mask(1:12), DAY_mask(1:31)
    LOGICAL*1 HOUR_mask(1:24), CODE_mask(1:30)
    LOGICAL*1 P_flag, LINK_flag(10), L_flag, P10_FLAG, P50_FLAG, P90_FLAG
    LOGICAL*1 Read_flag, Run_flag, Rept_flag, DAY_flag, HOUR_flag
    LOGICAL*1 MONTHLY_flag, Es_layer_flag, FIRST_flag

" *******************************************************************
" Define COMMON blocks

    COMMON/IONSNP/ foF2(31,24), M3000F2(31,24), hF2(31,24), foF1(31,24),-
                M3000F1(31,24), hF1(31,24), hF(31,24), foE(31,24),-
          hE(31,24), foEs(31,24), fbEs(31,24), fEs(31,24),-
          hEs(31,24), fmin(31,24), fxI(31,24)

    COMMON /LIMIT/ fMHz_low, fMHz_hgh, adg_low, adg_hgh, hkm_low, hkm_hgh,-
          N_FRQ, N_ANG, N_HGT, LNK_file, d_f, d_a, d_h, -
          D_km(1:10), N_DST, N_DISP

    COMMON /FRQBN/ fMHz_km_hr_bin(1:10,1:24,0:61), fMHz_km_bin(1:10,0:61), -
          f_limit(1:12,1:2), f_hr_bin(1:10,1:24,1:12), -
          f_bin(1:10,1:12)

    COMMON /ANGBN/ adg_km_hr_bin(1:10,1:24,0:61), adg_km_bin(1:10,0:61), -
          ANG_km_hr_frq(1:10,1:24,0:61,1:2)

    COMMON /HGTBN/ hkm_km_hr_bin(1:10,1:24,0:61), hkm_km_bin(1:10,0:61)

    COMMON /COUNT/ N_km_hr_F2(1:10,1:24), N_km_hr_F1(1:10,1:24), -
                N_km_hr_1E(1:10,1:24), N_km_hr_1Es(1:10,1:24), -
                N_km_hr_2E(1:10,1:24), N_km_hr_2Es(1:10,1:24), -
          N_km_F2(1:10), N_km_F1(1:10), N_km_1E(1:10), -
          N_km_1Es(1:10), N_km_2E(1:10), N_km_2Es(1:10), -
          N_km_hr_cutE(1:10,1:24), N_km_cutE(1:10), -
```

```
          N_km_hr_cutEs(1:10,1:24), N_km_cutEs(1:10), -
          N_km_hr(1:10,1:24), N_km(1:10)

" ***********************************************************************
" Initialize constants

   DATA P_index/1,2,3,4,5,6,4*0,7,8,0,9,10,0,11,3*0,-
              12,0,13,0,14,0,15,3*0,16,17,18,19,20,5*0,-
              21,0,22,23,24,5*0,25,26,27,17*0,28,29,30/

   DATA P_type/3*1,3,2*2,2*1,3,2,2,1,1,2,2,4*1,2,-
        1,1,3,2,3*1,3*1/

   DATA P_scale/10.0,1.0,100.0/

   DATA BLANK_line/'                    '/

   DATA P_names/'foF2','fxF2','fzF2','M(3000)F2','h"F2','fpF2',-
   'foF1','fxF1','M(3000)F1','h"F1','h"F','foE','foE2','h"E','h"E2',-
   'foEs','fxEs','fbEs','fEs','h"Es','foF1.5','fmin','M(3000)F1.5',-
   'h"f1.5','foI','fxI','fmI','I(2000)','I','I(xxx)'/

   DATA P_heading/' FRQ ',' HGT ','     '/
   DATA DIM_heading/'(MHz)',' (km)','FACTR','(deg)'/
   DATA HOUR_heading/' Universal Time in Hours '/
   DATA QUAL_heading/' QUAL'/
   DATA DESC_heading/' DESC'/
   DATA DIST_heading/'Path Length in Kilometers'/
   DATA L_heading/' FRQ ',' ANG ',' HGT '/
   DATA f_limit/2.0, 6.0, 10.0, 14.0, 18.0, -
          22.0, 26.0, 30.0, 40.0, 60.0, 100.0, 150.0, -
          6.0, 10.0, 14.0, 18.0, 22.0, 26.0, 30.0, -
          40.0, 60.0, 100.0, 150.0, 300.0/

   DATA N_DISP/12/

   DATA f_RANGE /'  2-6 ',' 6-10 ',' 10-14',' 14-18',' 18-22', -
          ' 22-26',' 26-30',' 30-40',' 40-60','60-100', -
          'to 150', 'to 300'/

" ***********************************************************************
" ***********************************************************************
" Open input file

   WRITE(6,*) 'Type name of input file with extension ".INP"'
   READ(6,700) file_INP
700  FORMAT(a20)
```

```
" Concatenate input and output file names

   INP_file = file_INP(1:LEN_TRIM(file_INP))//'.INP'
   OUT_file = file_INP(1:LEN_TRIM(file_INP))//'.OUT'
   LNK_file = file_INP(1:LEN_TRIM(file_INP))//'.LNK'

" Read input file

   OPEN(UNIT=2,STATUS='OLD',FILE=INP_file)
   READ(2,700) STATION_check
   READ(2,*) HOUR_i, DAY_i, MONTH_i, YEAR_i
   READ(2,*) HOUR_f, DAY_f, MONTH_f, YEAR_f
   READ(2,*) ( YEAR_mask(j), j = 1, 25 )
   READ(2,*) ( MONTH_mask(j), j = 1, 12 )
   READ(2,*) MONTHLY_flag
   READ(2,*) ( DAY_mask(j), j = 1, 31 )
   READ(2,*) ( HOUR_mask(j), j = 1, 24 )
   READ(2,*) N_DST, ( D_km(j), j = 1, N_DST )
   READ(2,*) fMHz_low, fMHz_hgh, N_FRQ, Es_layer_flag
   READ(2,*) hkm_low, hkm_hgh, N_HGT
   READ(2,*) adg_low, adg_hgh, N_ANG
   DO i = 1, 30
      READ(2,*) j, CODE_mask(j), P_low(j), P_hgh(j), N_Pbins(j)
   END DO
   READ(2,*) DIV_flag

" Read names of standard ionosonde files.  If an error occurs or if
" if no input filenames are present, output the appropriate message
" and stop execution

   i_FILE = 1

100 READ(2,700,ERR=998,END=999) ION_files(i_FILE)

" Determine the number of ionosonde input files

   DO WHILE ( i_FILE .GT. 0 )

      i_FILE = i_FILE + 1

      READ(2,700,END=102) ION_files(i_FILE)

   END DO

102 N_file = i_FILE - 1
```

```
     d_f = ( fMHz_hgh - fMHz_low ) / FLOAT( N_FRQ )
     d_a = ( adg_hgh - adg_low ) / FLOAT( N_ANG )
     d_h = ( hkm_hgh - hkm_low ) / FLOAT( N_HGT )

"  INITIALIZE all bin values to zero

     ANG_km_hr_frq = 0.0
     fMHz_km_hr_bin = 0.0
     hkm_km_hr_bin = 0.0
     adg_km_hr_bin = 0.0
     fMHz_km_bin = 0.0
     f_hr_bin = 0.0
     f_bin = 0.0
     hkm_km_bin = 0.0
     adg_km_bin = 0.0

     N_km_hr_F2 = 0.0
     N_km_hr_F1 = 0.0
     N_km_hr_1E = 0.0
     N_km_hr_1Es = 0.0
     N_km_hr_2E = 0.0
     N_km_hr_2Es = 0.0
     N_km_F2 = 0.0
     N_km_F1 = 0.0
     N_km_1E = 0.0
     N_km_1Es = 0.0
     N_km_2E = 0.0
     N_km_2Es = 0.0
     N_km_hr = 0.0
     N_km = 0.0

     N_months = 0
     N_code = 0

"  Initialize all ionosonde parameter storage locations to -1.0.  Note that
"  the commented parameters are not yet used in the calculation of forward
"  propagating signals.

     foF2 = -1.0
"      fxF2 = -1.0
"      fzF2 = -1.0
     M3000F2  = -1.0
     hF2   = -1.0
"      hpf2 = -1.0
     foF1 = -1.0
"      fxF1 = -1.0
     M3000F1 = -1.0
```

```
      hF1 = -1.0
      hF = -1.0
      foE = -1.0
"       foE2 = -1.0
      hE = -1.0
"       hE2 = -1.0
      foEs = -1.0
"       fxEs = -1.0
"       fbEs = -1.0
"       fEs = -1.0
      hEs = -1.0
"       foF1d5 = -1.0
      fmin = -1.0
"       M3000F1d5 = -1.0
"       hf1d5 = -1.0
"       foI = -1.0
"       fxI = -1.0
"       fmI = -1.0
"       I2000 = -1.0
"       Ixxx = -1.0

" ***********************************************************************
" START of FILE loop

      i_FILE = 0
      Run_flag = .TRUE.
      DO WHILE ( i_FILE .LT. N_FILE .AND. Run_flag )

          FIRST_flag = .TRUE.
          i_FILE = i_FILE + 1

" Open input files for ionosonde data, sunspot numbers, auroral electrojet
" indices, and vertical absorption

        OPEN(UNIT=4,STATUS='OLD',FILE=ION_files(i_FILE))

        IF ( MONTHLY_flag ) THEN
          OPEN(UNIT=5,STATUS='UNKNOWN',ACCESS='APPEND',FILE=LNK_file)
          WRITE(5,701) LNK_file, STATION_check
701         FORMAT(1x,'Input filename:  ',a30,' Link midpoint at ',a20 -
                /10x,'(All frequencies in MHz & ranges in km)')
        END IF

" Start of parameter loop

          Read_flag = .TRUE.
        DO WHILE ( Read_flag .AND. Run_flag )
```

```
" Read the next line of the current input file and check the first
" 21 characters to make sure they are nonblank. If they are blank,
" then a new record should be read.

      RECORD_I(1:21) = BLANK_line
      DO WHILE( RECORD_I(1:21) .EQ. BLANK_line )
        READ(4,702,END=200) RECORD_I
      END DO
702     FORMAT(a120)

" Extract station name, code, standard time meridian, geographic co-latitude,
" east longitude, year, month, and the parameter code

        STATION_name = RECORD_I(1:20)
      IF ( STATION_name .NE. STATION_check ) THEN
        WRITE(6,*) 'Station name does not match input name!'
        CYCLE
      END IF

      STATION_code = RECORD_I(21:26)
      TIME_meridian = RECORD_I(26:29)
      STATION_COLAT_ddg = RECORD_I(30:33)
      STATION_ELNG_ddg = RECORD_I(34:37)
      YEAR = RECORD_I(38:41)
      Y_1 = ICHAR( RECORD_I(38:38) ) - 48
      Y_2 = ICHAR( RECORD_I(39:39) ) - 48
      Y_3 = ICHAR( RECORD_I(40:40) ) - 48
      Y_4 = ICHAR( RECORD_I(41:41) ) - 48
      i_YEAR = 1000 * Y_1 + 100 * Y_2 + 10 * Y_3 + Y_4
      IF ( i_YEAR .LT. YEAR_i .OR. i_YEAR .GT. YEAR_f .OR.-
         .NOT. YEAR_mask(i_FILE) ) THEN
        Read_flag = .FALSE.
        CYCLE
      END IF

      MONTH = RECORD_I(42:43)
      M_1 = ICHAR( RECORD_I(42:42) ) - 48
      M_2 = ICHAR( RECORD_I(43:43) ) - 48
        i_MONTH = 10 * M_1 + M_2
        IF ( FIRST_flag ) j_MONTH = i_MONTH

        IF ( i_YEAR .EQ. YEAR_f .AND. i_MONTH .GT. MONTH_f ) THEN
        Read_flag = .FALSE.
        CYCLE
      END IF
```

```
IF ( .NOT. MONTH_mask( i_MONTH ) .OR. -
   ( i_YEAR .EQ. YEAR_i .AND. i_MONTH .LT. MONTH_i ) ) THEN
    DO i = 1, 31
    READ(4,702,END=200) RECORD_I
    END DO
  CYCLE
  END IF

P_code(1) = ICHAR( RECORD_I(44:44) ) - 48
P_code(2) = ICHAR( RECORD_I(45:45) ) - 48
  PARM_code = 10 * P_code(1) + P_code(2)
  i_CODE = P_index( PARM_code + 1 )

  IF ( FIRST_flag .AND. i_CODE .GT. N_code ) THEN

    N_code = i_CODE

  ELSE IF ( ( FIRST_flag .AND. i_CODE .LE. N_code ) -
          .OR. ( .NOT. FIRST_flag .AND. -
                i_MONTH .NE. month_OLD ) ) THEN

        DO i_DAY = 1, 31
          DO i_HOUR = 1, 24
        CALL HFLINKS( i_DAY, i_HOUR, LINK_flag, -
                Es_layer_flag, MONTHLY_flag )
          END DO
        END DO

        if ( month_OLD .EQ. 0 ) month_OLD = i_MONTH - 1

        IF ( MONTHLY_flag ) THEN
          CALL NRMLYZE( i_YEAR, month_OLD, MONTHLY_flag )
        END IF

        N_months = N_months + 1
        month_OLD = i_MONTH
        FIRST_flag = .FALSE.
    OLD_MONTH = MONTH

        WRITE(6,*) YEAR, ' ', OLD_MONTH, ' ', N_months, -
                ' ', INP_file, ION_files( i_FILE )

END IF

  IF ( .NOT. CODE_mask( i_CODE ) ) THEN
    DO i = 1, 31
       READ(4,702,END=200) RECORD_I
```

```
          END DO
          CYCLE
        END IF

        WRITE(6,*) 'MONTH:  ', i_MONTH, ' CODE:  ', RECORD_I(44:45)

"  Determine the upper and lower bin limits of the parameter for either
"  frequency (i_DIM = 1) or height (i_DIM = 2)

        i_DIM = P_type( i_CODE )
        N_bins = N_Pbins( i_DIM )

"  Compute parameter increment value

      d_P = ( P_hgh(i_CODE) - P_low(i_CODE) ) -
          / FLOAT( N_Pbins(i_CODE) )

"  START loop for each day of the current month

      i_DAY = 0
      DAY_flag = .TRUE.

      DO WHILE ( i_DAY .LT. 31 .AND. DAY_flag )

        i_DAY = i_DAY + 1

"  Read next input record and divide into 24 5-character strings
"  Check the first 20 characters to make sure they are nonblank.  If they
"  are blank, then a new record should be read.

        READ(4,702,END=997) RECORD_I

"  Check to see if current day is within interval to be processed.

        IF ( ( i_YEAR .EQ. YEAR_i .AND. i_MONTH .EQ. MONTH_i -
            .AND. i_DAY .LT. DAY_i ) .OR. -
            .NOT. DAY_mask(i_DAY) ) CYCLE

        IF ( i_YEAR .EQ. YEAR_f .AND. i_MONTH .EQ. MONTH_f -
            .AND. i_DAY .GT. DAY_f ) THEN
          DAY_flag = .FALSE.
          Read_flag = .FALSE.
          CYCLE
        END IF

"  START loop for each hour of the current day.
```

```
        HOUR_flag = .TRUE.
        i_HOUR = 0
        DO WHILE ( i_HOUR .LT. 24 .AND. HOUR_flag )

          i_HOUR = i_HOUR + 1

              P_value = 0.0

" Check to see if current hour is within interval to be processed

          IF ( ( i_YEAR .EQ. YEAR_i .AND. i_MONTH .EQ. MONTH_i -
              .AND. i_DAY .EQ. DAY_i .AND. i_HOUR .LT. HOUR_i ) -
                 .OR. .NOT. HOUR_mask(i_HOUR) ) CYCLE

          IF ( i_YEAR .EQ. YEAR_f .AND. i_MONTH .EQ. MONTH_f -
            .AND. i_DAY .EQ. DAY_f .AND. i_HOUR .GT. HOUR_f ) THEN
            HOUR_flag = .FALSE.
            DAY_flag = .FALSE.
            Rept_flag = .FALSE.
            CYCLE
          END IF

          k_CHAR = 5 * ( i_HOUR - 1 ) + 1

              IF ( RECORD_I(k_CHAR:k_CHAR+4) .EQ. '     ' ) CYCLE

" Read scaled parameter for the current hour at the ionosonde

          P_char(1) = RECORD_I(k_CHAR:k_CHAR)
          P_char(2) = RECORD_I(k_CHAR+1:k_CHAR+1)
          P_char(3) = RECORD_I(k_CHAR+2:k_CHAR+2)
          Q_char = RECORD_I(k_CHAR+3:k_CHAR+3)
          D_char = RECORD_I(k_CHAR+4:k_CHAR+4)

          IF ( P_char(1) .NE. ' ' ) THEN

                P_1 = REAL( ICHAR( P_char(1) ) - 48 )
                P_2 = REAL( ICHAR( P_char(2) ) - 48 )
                P_3 = REAL( ICHAR( P_char(3) ) - 48 )
                P_flag = .TRUE.

              ELSE IF ( P_char(2) .NE. ' ' ) THEN

                    P_1 = 0.0
                    P_2 = REAL( ICHAR( P_char(2) ) - 48 )
                    P_3 = REAL( ICHAR( P_char(3) ) - 48 )
                    P_flag = .TRUE.
```

```
        ELSE IF ( P_char(3) .NE. ' ' ) THEN

                P_1 = 0.0
                P_2 = 0.0
                P_3 = REAL( ICHAR( P_char(3) ) - 48 )
                P_flag = .TRUE.

      ELSE

        P_value = 0.0
            P_flag = .FALSE.

      END IF

      IF ( P_flag ) THEN

        P_value = ( 100.0*P_1 + 10.0*P_2 + P_3 )-
              / P_scale(i_DIM)

      END IF

          IF ( P_flag ) THEN

            CALL PARMBIN( i_DAY, i_HOUR, i_CODE, P_value, -
                      Q_char, D_char )
          END IF

" End of hourly loop for current day, parameter, month, and year (file)

        END DO

" End of daily loop for current parameter, month, and year (file).

        END DO

" End of current parameter & month loop for year (file).

       END DO

" All input records in the current input file have been read.  Proceed
" to next input file

200    CLOSE(UNIT=4)

" Input results from next year (or file)
```

```
      END DO

"  Compute HF links for last month

      DO i_DAY = 1, 31
         DO i_HOUR = 1, 24
         CALL HFLINKS( i_DAY, i_HOUR, LINK_flag, Es_layer_flag, -
                  MONTHLY_flag )
       END DO
      END DO

      N_months = N_months + 1

      IF ( MONTHLY_flag ) THEN
         CALL NRMLYZE( i_YEAR, month_OLD, MONTHLY_flag )
      END IF

      month_OLD = i_MONTH
      FIRST_flag = .FALSE.

      WRITE(6,*) YEAR, ' ', MONTH, ' ', N_months, -
               ' ', INP_file, ION_files( i_FILE )

"  Output the probability distributions for each parameter code, both
"  for each hour and over all hours in a column format

      IF ( .NOT. MONTHLY_flag ) THEN

"  All input files have been read.  Normalize each distribution count
"  by the numbers of samples for each paramater code.

         CALL NRMLYZE( i_YEAR, i_MONTH, MONTHLY_flag )

         OPEN(UNIT=3,STATUS='UNKNOWN',ACCESS='APPEND',FILE=OUT_file)

       WRITE(3,704) STATION_name
704    FORMAT(/25x,'IONOSONDE PARAMETER STATISTICS AT ', a20)

       WRITE(3,705) HOUR_i, DAY_i, MONTH_i, YEAR_i, HOUR_f, DAY_f,-
              MONTH_f, YEAR_f
705    FORMAT(/10x,'IONOSONDE measurements processed for the period:  ',-
          3(i2,', '),i4,' to ',3(i2,', '),i4)

"  Output HF link propagation characteristics.

       WRITE(3,730)
730    FORMAT('1'//10x,'HF LINK PROPAGATION VERSUS HOUR & PATH LENGTH')
```

```
" Output hourly results for each range

      DO i_DST = 1, N_DST

        WRITE(3,734) D_km(i_DST), 'LAYER', ( i, i = 1, 24 )
734       FORMAT(//5x,'PERCENTAGE OF HOURS VS REFLECTING LAYER & HOUR' -
            //5x,'          Link Range:  ', f7.1, -
                //1x, a5, 49x, 'Hour of the day' -
            / 7x, 24( 1x, i3, 1x ), ' NET ' )
        WRITE(3,736) '  F2 ', (N_km_hr_F2(i_DST,i_HOUR),i_HOUR=1,24),-
                N_km_F2(i_DST)
        WRITE(3,736) '  F1 ', (N_km_hr_F1(i_DST,i_HOUR),i_HOUR=1,24),-
                N_km_F1(i_DST)
        WRITE(3,736) '  1E ', (N_km_hr_1E(i_DST,i_HOUR),i_HOUR=1,24),-
                N_km_1E(i_DST)
        WRITE(3,736) '  2E ', (N_km_hr_2E(i_DST,i_HOUR),i_HOUR=1,24),-
                N_km_2E(i_DST)
        WRITE(3,736) ' 1Es ', (N_km_hr_1Es(i_DST,i_HOUR),i_HOUR=1,24),-
                N_km_1Es(i_DST)
        WRITE(3,736) ' 2Es ', (N_km_hr_2Es(i_DST,i_HOUR),i_HOUR=1,24),-
                N_km_2Es(i_DST)
        WRITE(3,736) 'cutE ', (N_km_hr_cutE(i_DST,i_HOUR),i_HOUR=1,24),-
                N_km_cutE(i_DST)
        WRITE(3,736) 'cutEs', (N_km_hr_cutEs(i_DST,i_HOUR),i_HOUR=1,24),-
                N_km_cutEs(i_DST)
736       FORMAT( 1x, a6, 25f5.3 )

        WRITE(3,732)
732       FORMAT(//10x,'***** MAXIMUM USABLE FREQUENCY *****')
        WRITE(3,738) D_km(i_DST), ' FREQ ', ( i, i = 0, 24 )
738       FORMAT(//5x,'          Link Range:  ', f7.1, -
                //1x, a6, 48x,'Hour of the day (UT)' -
            /2x, 25( i3, 2x ), ' NET ' )

        DO i_DISP = 1, N_DISP

          WRITE(3,742) f_RANGE(i_DISP), -
            ( f_hr_bin(i_DST,i_HOUR,i_DISP),i_HOUR=1,24), -
             f_bin(i_DST,i_DISP)
742         FORMAT( 1x, a6, 25f5.3 )

        END DO

        WRITE(3,746)
746       FORMAT('1'//10x,'***** RAY ELEVATION ANGLE *****')
          WRITE(3,748) D_km(i_DST), 'ANGLE ', ( i, i = 1, 24 )
```

```
748      FORMAT(//5x, '          Link Range:  ', f7.1, -
               //1x, a6, 48x, 'Hour of the day' -
               /7x, 24( i3, 2x ), ' NET ' )

      DO i_ANG = 0, N_ANG

        a_dg = adg_low + i_ANG * d_a

        WRITE(3,752) a_dg, -
               (adg_km_hr_bin(i_DST,i_HOUR,i_ANG),i_HOUR=1,24), -
               adg_km_bin(i_DST,i_ANG)
752       FORMAT( 1x, f6.2, 25f5.3 )

      END DO

      WRITE(3,754) (adg_km_hr_bin(i_DST,i_HOUR,N_ANG+1),i_HOUR=1,24), -
             adg_km_bin(i_DST,N_ANG+1)
754      FORMAT( 1x, '  >  ', 25f5.3 )

      WRITE(3,756)
756      FORMAT('1'//10x,'***** VIRTUAL REFLECTION HEIGHT *****')

       WRITE(3,758) D_km(i_DST), 'HEIGHT', ( i, i = 1, 24 )
758      FORMAT(//5x, '          Link Range:  ', f7.1, -
               //1x, a6, 48x, 'Hour of the day' -
               /7x, 24( i3, 2x ), ' NET ' )

      DO i_HGT = 0, N_HGT

        h_km = hkm_low + i_HGT * d_h

        WRITE(3,762) h_km, -
               (hkm_km_hr_bin(i_DST,i_HOUR,i_HGT),i_HOUR=1,24), -
               hkm_km_bin(i_DST,i_HGT)
762       FORMAT( 1x, f6.1, 25f5.3 )

      END DO

      WRITE(3,764) (hkm_km_hr_bin(i_DST,i_HOUR,N_HGT+1),i_HOUR=1,24), -
             hkm_km_bin(i_DST,N_HGT+1)
764      FORMAT(1x,'  >  ', 25f5.3 )

"  End of distance loop

    END DO

  END IF
```

```
      CLOSE(UNIT=2)

      IF ( MONTHLY_flag ) THEN
        CLOSE(UNIT=5)
      ELSE
        CLOSE(UNIT=3)
      END IF

      STOP

997   WRITE(6,*) 'Error on input, probably wrong number of -
                  characters in record'
      CLOSE(UNIT=2)
      CLOSE(UNIT=3)
      STOP

998   WRITE(6,*) 'Error on input, probably no access to input file'
      CLOSE(UNIT=2)
      CLOSE(UNIT=3)
      STOP

999   WRITE(6,*) 'No ionosonde input files were listed'
      CLOSE(UNIT=2)
      CLOSE(UNIT=3)
      STOP

      END



      SUBROUTINE NRMLYZE( i_YEAR, i_MONTH, MONTHLY_flag )

      REAL*4 fMHz_km_hr_bin, adg_km_hr_bin, hkm_km_hr_bin, M_H
      REAL*4 N_km_hr_F2, N_km_hr_F1, N_km_hr_1E, N_km_hr_1Es, N_km_hr_2E
      REAL*4 N_km_hr_2Es, fMHz_km_bin, adg_km_bin, hkm_km_bin
      REAL*4 N_km_F2, N_km_F1, N_km_1E, N_km_1Es, N_km_2E, N_km_2Es
      REAL*4 m_MUF, b_MUF, DUM_1, DUM_2, N_km_hr, N_km
      REAL*4 MUF_10(1:10,1:24), MUF_50(1:10,1:24), MUF_90(1:10,1:24)
      REAL*4 ANG_10(1:10,1:24), ANG_50(1:10,1:24)
      REAL*4 N_km_hr_cutE, N_km_hr_cutEs, N_km_cutE, N_km_cutEs
      REAL*4 ANG_90(1:10,1:24), ANG_km_hr_frq, d_f, d_a, d_h
      REAL*4 f_limit, f_hr_bin, f_bin

      INTEGER*4 i_DAY, i_HOUR, i_DST, i_YEAR, i_MONTH, N_DISP
      INTEGER*4 N_DST, N_FRQ, N_bins, N_HGT, N_ANG, month_OLD
```

```
LOGICAL*1 P10_FLAG, P50_FLAG, P90_FLAG, MONTHLY_flag, NONZERO_flag

CHARACTER*20 LNK_file

COMMON/IONSNP/ foF2(31,24), M3000F2(31,24), hF2(31,24), foF1(31,24),-
        M3000F1(31,24), hF1(31,24), hF(31,24), foE(31,24),-
    hE(31,24), foEs(31,24), fbEs(31,24), fEs(31,24),-
    hEs(31,24), fmin(31,24), fxI(31,24)

COMMON /LIMIT/ fMHz_low, fMHz_hgh, adg_low, adg_hgh, hkm_low, hkm_hgh,-
    N_FRQ, N_ANG, N_HGT, LNK_file, d_f, d_a, d_h, -
    D_km(1:10), N_DST, N_DISP

COMMON /FRQBN/ fMHz_km_hr_bin(1:10,1:24,0:61), fMHz_km_bin(1:10,0:61), -
    f_limit(1:12,1:2), f_hr_bin(1:10,1:24,1:12), -
    f_bin(1:10,1:12)

COMMON /ANGBN/ adg_km_hr_bin(1:10,1:24,0:61), adg_km_bin(1:10,0:61), -
    ANG_km_hr_frq(1:10,1:24,0:61,1:2)

COMMON /HGTBN/ hkm_km_hr_bin(1:10,1:24,0:61), hkm_km_bin(1:10,0:61)

COMMON /COUNT/ N_km_hr_F2(1:10,1:24), N_km_hr_F1(1:10,1:24), -
        N_km_hr_1E(1:10,1:24), N_km_hr_1Es(1:10,1:24), -
        N_km_hr_2E(1:10,1:24), N_km_hr_2Es(1:10,1:24), -
    N_km_F2(1:10), N_km_F1(1:10), N_km_1E(1:10), -
    N_km_1Es(1:10), N_km_2E(1:10), N_km_2Es(1:10), -
    N_km_hr_cutE(1:10,1:24), N_km_cutE(1:10), -
    N_km_hr_cutEs(1:10,1:24), N_km_cutEs(1:10), -
    N_km_hr(1:10,1:24), N_km(1:10)

DO i_DST = 1, N_DST

  IF ( N_km(i_DST) .NE. 0.0 ) THEN

    N_km_F2(i_DST) = N_km_F2(i_DST) / N_km(i_DST)
    N_km_F1(i_DST) = N_km_F1(i_DST) / N_km(i_DST)
    N_km_1E(i_DST) = N_km_1E(i_DST) / N_km(i_DST)
    N_km_2E(i_DST) = N_km_2E(i_DST) / N_km(i_DST)
    N_km_1Es(i_DST) = N_km_1Es(i_DST) / N_km(i_DST)
    N_km_2Es(i_DST) = N_km_2Es(i_DST) / N_km(i_DST)
    N_km_cutE(i_DST) = N_km_cutE(i_DST) / N_km(i_DST)
    N_km_cutEs(i_DST) = N_km_cutEs(i_DST) / N_km(i_DST)

    DO i_FRQ = 0, N_FRQ + 1

      fMHz_km_bin(i_DST,i_FRQ) = fMHz_km_bin(i_DST,i_FRQ) -
```

```
                  / N_km(i_DST)

    IF ( i_FRQ .GT. 0 .AND. MONTHLY_flag ) -
      fMHz_km_bin(i_DST,i_FRQ) = fMHz_km_bin(i_DST,i_FRQ) -
                   + fMHz_km_bin(i_DST,i_FRQ-1)

  END DO

    DO i_ANG = 0, N_ANG + 1

    adg_km_bin(i_DST,i_ANG) = adg_km_bin(i_DST,i_ANG) -
                  / N_km(i_DST)
    IF ( i_ANG .GT. 0 .AND. MONTHLY_flag ) -
      adg_km_bin(i_DST,i_ANG) = adg_km_bin(i_DST,i_ANG) -
                   + adg_km_bin(i_DST,i_ANG-1)

  END DO

    DO i_HGT = 0, N_HGT + 1

    hkm_km_bin(i_DST,i_HGT) = hkm_km_bin(i_DST,i_HGT) -
                  / N_km(i_DST)
    IF ( i_HGT .GT. 0 .AND. MONTHLY_flag ) -
      hkm_km_bin(i_DST,i_HGT) = hkm_km_bin(i_DST,i_HGT) -
                   + hkm_km_bin(i_DST,i_HGT-1)

  END DO

  DO i_DISP = 1, N_DISP

    f_bin(i_DST,i_DISP) = f_bin(i_DST,i_DISP) / N_km(i_DST)

  END DO

END IF

  DO i_HOUR = 1, 24

  IF ( N_km_hr(i_DST,i_HOUR) .NE. 0.0 ) THEN

    N_km_hr_F2(i_DST,i_HOUR) = N_km_hr_F2(i_DST,i_HOUR) / -
                   N_km_hr(i_DST,i_HOUR)
    N_km_hr_F1(i_DST,i_HOUR) = N_km_hr_F1(i_DST,i_HOUR) / -
                   N_km_hr(i_DST,i_HOUR)
    N_km_hr_1E(i_DST,i_HOUR) = N_km_hr_1E(i_DST,i_HOUR) / -
                   N_km_hr(i_DST,i_HOUR)
    N_km_hr_2E(i_DST,i_HOUR) = N_km_hr_2E(i_DST,i_HOUR) / -
```

```
                  N_km_hr(i_DST,i_HOUR)
N_km_hr_1Es(i_DST,i_HOUR) = N_km_hr_1Es(i_DST,i_HOUR) / -
                  N_km_hr(i_DST,i_HOUR)
N_km_hr_2Es(i_DST,i_HOUR) = N_km_hr_2Es(i_DST,i_HOUR) / -
                  N_km_hr(i_DST,i_HOUR)
  N_km_hr_cutE(i_DST,i_HOUR) = -
        N_km_hr_cutE(i_DST,i_HOUR) / N_km_hr(i_DST,i_HOUR)
  N_km_hr_cutEs(i_DST,i_HOUR) = -
        N_km_hr_cutEs(i_DST,i_HOUR) / N_km_hr(i_DST,i_HOUR)

  DO i_FRQ = 0, N_FRQ + 1

  fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ) = -
                     fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ) / -
                          N_km_hr(i_DST,i_HOUR)
  IF ( i_FRQ .GT. 0 .AND. MONTHLY_flag ) -
    fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ) = -
              fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ) -
              + fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ-1)

END DO

DO i_ANG = 0, N_ANG + 1

  adg_km_hr_bin(i_DST,i_HOUR,i_ANG) = -
                     adg_km_hr_bin(i_DST,i_HOUR,i_ANG) / -
                          N_km_hr(i_DST,i_HOUR)
  IF ( i_ANG .GT. 0 .AND. MONTHLY_flag ) -
    adg_km_hr_bin(i_DST,i_HOUR,i_ANG) = -
              adg_km_hr_bin(i_DST,i_HOUR,i_ANG) -
              + adg_km_hr_bin(i_DST,i_HOUR,i_ANG-1)

END DO

DO i_HGT = 0, N_HGT + 1

  hkm_km_hr_bin(i_DST,i_HOUR,i_HGT) = -
                     hkm_km_hr_bin(i_DST,i_HOUR,i_HGT) / -
                          N_km_hr(i_DST,i_HOUR)

END DO

DO i_DISP = 1, N_DISP

  f_hr_bin(i_DST,i_HOUR,i_DISP) = -
              f_hr_bin(i_DST,i_HOUR,i_DISP) / -
                   N_km_hr(i_DST,i_HOUR)
```

```
        END DO

      END IF

    END DO

  END DO

" Exit if statistics are not being collected monthly.

  IF ( .NOT. MONTHLY_flag ) RETURN

" Compute tenth, fiftieth, and ninetieth percentiles for the link MUF
" add results to the LNK_file

  DO i_DST = 1, N_DST

      DO i_HOUR = 1, 24

"       WRITE(6,*) 'NEW i_HOUR: ', i_HOUR
"       WRITE(5,*) 'NEW i_HOUR: ', i_HOUR

        DO i_FRQ = 0, N_FRQ+1

          DUM_2 = fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ)
          DUM_1 = fMHz_km_hr_bin(i_DST,i_HOUR,N_FRQ+1)

          IF ( DUM_1 .NE. 0.0 ) THEN
              fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ) = DUM_2 / DUM_1
          ELSE
              fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ) = 0.0
          END IF

        f = fMHz_low + FLOAT( i_FRQ-1) * d_f + 0.5 * d_f

"        WRITE(6,*) i_HOUR, i_FRQ, f, -
"               fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ), -
"               ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,1)
"        WRITE(5,*) i_HOUR, i_FRQ, f, -
"               fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ), -
"               ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,1)

        END DO

        P10_FLAG = .FALSE.
      P50_FLAG = .FALSE.
```

```
P90_FLAG = .FALSE.

  DO i_FRQ = 1, N_FRQ-1

    x2 = fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ+1)

    IF ( x2 .GT. 0.10 .AND. .NOT. P10_FLAG ) THEN

        P10_FLAG = .TRUE.

        x1 = fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ)
        y1 = fMHz_low + ( FLOAT( i_FRQ - 1 ) + 0.5 ) * d_f
        y2 = y1 + d_f

        DUM_1 = x2 - x1

        IF ( DUM_1 .NE. 0.0 ) THEN
          m_MUF = ( y2 - y1 ) / DUM_1
          b_MUF = ( y1 * x2 - y2 * x1 ) / DUM_1
          DUM_2 = m_MUF * 0.10 + b_MUF
        ELSE
          DUM_2 = fMHz_low + ( FLOAT( i_FRQ - 1 ) + 0.5 ) * d_f
        END IF

        IF ( DUM_2 .GE. fMHz_low ) THEN
          MUF_10(i_DST,i_HOUR) = DUM_2
        ELSE
          MUF_10(i_DST,i_HOUR) = fMHz_low + 0.5 * d_f
    END IF

    DUM_1 = ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,1)

    IF ( DUM_1 .GT. 0.0 ) THEN

          DUM_2 = ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,2)
      ANG_10(i_DST,i_HOUR) = DUM_2 / DUM_1

    ELSE

" Determine average angle below current MUF10 frequency

      DUM_1 = 0.0
      DUM_2 = 0.0
      NONZERO_flag = .FALSE.
      DO j_FRQ = i_FRQ-1, 1, -1
        IF ( NONZERO_flag ) THEN
          CYCLE
```

```
    ELSE
      DUM_1 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,1)
      IF ( DUM_1 .NE. 0.0 ) THEN
        NONZERO_flag = .TRUE.
        DUM_2 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,2)
      END IF
    END IF
  END DO

" Determine average angle above current MUF10 frequency

  DUM_3 = 0.0
  DUM_4 = 0.0
  NONZERO_flag = .FALSE.
  DO j_FRQ = i_FRQ+1, N_FRQ
    IF ( NONZERO_flag ) THEN
      CYCLE
    ELSE
      DUM_3 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,1)
      IF ( DUM_3 .NE. 0.0 ) THEN
        NONZERO_flag = .TRUE.
        DUM_4 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,2)
      END IF
    END IF
  END DO

  DUM_5 = DUM_1 + DUM_3
  IF ( DUM_5 .NE. 0.0 ) THEN
    DUM_6 = DUM_2 + DUM_4
    ANG_10(i_DST,i_HOUR) = DUM_6 / DUM_5
  END IF

END IF

END IF

IF ( x2 .GT. 0.50 .AND. .NOT. P50_FLAG ) THEN

P50_FLAG = .TRUE.

   x1 = fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ)
   y1 = fMHz_low + ( FLOAT( i_FRQ - 1 ) + 0.5 ) * d_f
   y2 = y1 + d_f

DUM_1 = x2 - x1

IF ( DUM_1 .NE. 0.0 ) THEN
```

```
          m_MUF = ( y2 - y1 ) / DUM_1
          b_MUF = ( y1 * x2 - y2 * x1 ) / DUM_1
          DUM_2 = m_MUF * 0.50 + b_MUF
        ELSE
          DUM_2 = fMHz_low + ( FLOAT( i_FRQ - 1 ) + 0.5 ) * d_f
        END IF

        IF ( DUM_2 .GE. fMHz_low ) THEN
          MUF_50(i_DST,i_HOUR) = DUM_2
        ELSE
          MUF_50(i_DST,i_HOUR) = fMHz_low + 0.5 * d_f
        END IF

      DUM_1 = ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,1)

      IF ( DUM_1 .GT. 0.0 ) THEN

        DUM_2 = ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,2)
        ANG_50(i_DST,i_HOUR) = DUM_2 / DUM_1

      ELSE

"  Determine average angle below current MUF50 frequency

        DUM_1 = 0.0
        DUM_2 = 0.0
        NONZERO_flag = .FALSE.
        DO j_FRQ = i_FRQ-1, 1, -1
          IF ( NONZERO_flag ) THEN
            CYCLE
          ELSE
            DUM_1 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,1)
            IF ( DUM_1 .NE. 0.0 ) THEN
              NONZERO_flag = .TRUE.
              DUM_2 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,2)
            END IF
          END IF
        END DO

"  Determine average anlge above current MUF50 frequency

        DUM_3 = 0.0
        DUM_4 = 0.0
        NONZERO_flag = .FALSE.
        DO j_FRQ = i_FRQ+1, N_FRQ
          IF ( NONZERO_flag ) THEN
            CYCLE
```

```
    ELSE
      DUM_3 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,1)
      IF ( DUM_3 .NE. 0.0 ) THEN
        NONZERO_flag = .TRUE.
        DUM_4 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,2)
      END IF
    END IF
  END DO

  DUM_5 = DUM_1 + DUM_3
  IF ( DUM_5 .NE. 0.0 ) THEN
    DUM_6 = DUM_2 + DUM_4
    ANG_50(i_DST,i_HOUR) = DUM_6 / DUM_5
  END IF

 END IF

END IF

IF ( x2 .GT. 0.90 .AND. .NOT. P90_FLAG ) THEN

 P90_FLAG = .TRUE.

     x1 = fMHz_km_hr_bin(i_DST,i_HOUR,i_FRQ)
     y1 = fMHz_low + ( FLOAT( i_FRQ - 1 ) + 0.5 ) * d_f
     y2 = y1 + d_f

 DUM_1 = x2 - x1

 IF ( DUM_1 .NE. 0.0 ) THEN
       m_MUF = ( y2 - y1 ) / DUM_1
       b_MUF = ( y1 * x2 - y2 * x1 ) / DUM_1
       DUM_2 = m_MUF * 0.90 + b_MUF
     ELSE
       DUM_2 = fMHz_low + ( FLOAT( i_FRQ - 1 ) + 0.5 ) * d_f
     END IF

     IF ( DUM_2 .GE. fMHz_low ) THEN
       MUF_90(i_DST,i_HOUR) = DUM_2
     ELSE
       MUF_90(i_DST,i_HOUR) = fMHz_low + 0.5 * d_f
     END IF

 DUM_1 = ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,1)

 IF ( DUM_1 .GT. 0.0 ) THEN
```

```
        DUM_2 = ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,2)
        ANG_90(i_DST,i_HOUR) = DUM_2 / DUM_1

      ELSE

" Determine average angle below current MUF90 frequency

        DUM_1 = 0.0
        DUM_2 = 0.0
        NONZERO_flag = .FALSE.
        DO j_FRQ = i_FRQ-1, 1, -1
          IF ( NONZERO_flag ) THEN
            CYCLE
          ELSE
            DUM_1 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,1)
            IF ( DUM_1 .NE. 0.0 ) THEN
              NONZERO_flag = .TRUE.
              DUM_2 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,2)
            END IF
          END IF
        END DO

" Determine average angle above current MUF90 frequency

        DUM_3 = 0.0
        DUM_4 = 0.0
        NONZERO_flag = .FALSE.
        DO j_FRQ = i_FRQ+1, N_FRQ
          IF ( NONZERO_flag ) THEN
            CYCLE
          ELSE
            DUM_3 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,1)
            IF ( DUM_3 .NE. 0.0 ) THEN
              NONZERO_flag = .TRUE.
              DUM_4 = ANG_km_hr_frq(i_DST,i_HOUR,j_FRQ,2)
            END IF
          END IF
        END DO

        DUM_5 = DUM_1 + DUM_3
        IF ( DUM_5 .NE. 0.0 ) THEN
          DUM_6 = DUM_2 + DUM_4
          ANG_90(i_DST,i_HOUR) = DUM_6 / DUM_5
        END IF

      END IF
```

```
          END IF

          IF ( P10_FLAG .AND. P50_FLAG .AND. P90_FLAG ) CYCLE

        END DO

      END DO

    END DO

" Output results by appending to disk file
" OUTPUT MUF values exceeded 90% of the time

    WRITE(5,700) 'RANGE', i_YEAR, i_MONTH, 0, ( i, i = 0, 24 )
700  FORMAT(/2x, a5, 7x, ' 10% NOT EXCEEDED (FOT)', 1x, i4, 1x, i2, -
          /2x, 26( 1x, i3, 1x ) )

    DO i_DST = 1, N_DST
        WRITE(5,702) D_km(i_DST), MUF_10(i_DST,24), -
                (MUF_10(i_DST,i_HOUR),i_HOUR=1,24), -
            ANG_10(i_DST,24), -
            (ANG_10(i_DST,i_HOUR),i_HOUR=1,24)
702     FORMAT( 1x, f6.1, 25f5.1 /1x, 6x, 25f5.1 )
    END DO

" OUTPUT MUF values exceeded 50% of the time

    WRITE(5,704) 'RANGE', 0, ( i, i = 0, 24 )
704  FORMAT(2x, a5, 7x, ' 50% NOT EXCEEDED (FOT)', -
          /2x, 26( 1x, i3, 1x ) )

    DO i_DST = 1, N_DST
        WRITE(5,702) D_km(i_DST), MUF_50(i_DST,24), -
                (MUF_50(i_DST,i_HOUR),i_HOUR=1,24), -
            ANG_50(i_DST,24), -
            (ANG_50(i_DST,i_HOUR),i_HOUR=1,24)
    END DO

" OUTPUT MUF values exceeded 10% of the time

    WRITE(5,708) 'RANGE', 0, ( i, i = 0, 24 )
708  FORMAT(2x, a5, 7x, ' 90% NOT EXCEEDED (FOT)', -
          /2x, 26( 1x, i3, 1x ) )

    DO i_DST = 1, N_DST
        WRITE(5,702) D_km(i_DST), MUF_90(i_DST,24), -
                (MUF_90(i_DST,i_HOUR),i_HOUR=1,24), -
```

```
            ANG_90(i_DST,24), -
            (ANG_90(i_DST,i_HOUR),i_HOUR=1,24)
      END DO

      fMHz_km_hr_bin = 0.0
      hkm_km_hr_bin = 0.0
      adg_km_hr_bin = 0.0
      fMHz_km_bin = 0.0
      hkm_km_bin = 0.0
      adg_km_bin = 0.0
      ANG_km_hr_frq = 0.0
      MUF_10 = 0.0
      MUF_50 = 0.0
      MUF_90 = 0.0
      ANG_10 = 0.0
      ANG_50 = 0.0
      ANG_90 = 0.0
      N_km_hr_F2 = 0.0
      N_km_hr_F1 = 0.0
      N_km_hr_1E = 0.0
      N_km_hr_1Es = 0.0
      N_km_hr_2E = 0.0
      N_km_hr_2Es = 0.0
      N_km_F2 = 0.0
      N_km_F1 = 0.0
      N_km_1E = 0.0
      N_km_1Es = 0.0
      N_km_2E = 0.0
      N_km_2Es = 0.0
      N_km_hr = 0.0
      N_km = 0.0

      RETURN

      END
```

B.3.2 HFLINKS.FOR Source Program

```
$FREEFORM
$LARGE

"                         Subroutine HFLINKS
"
" Purpose:      Process an IONOSONDE data file following the conventions
"               established in UAG-23 and UAG-23A and determine the optimum
"               frequencies for an HF communications link with its midpath
"               above the ionosonde.

    SUBROUTINE HFLINKS( i_DAY, i_HOUR, LINK_flag, Es_layer_flag, -
                 MONTHLY_flag )

" Declare variable types and dimension arrays

" Define parameters for MUF calculation

    REAL h_LINK_km, f_LINK_MHz, a_LINK_dg, D_km, ANG_km_hr_frq

    REAL*4 MUF_fctr, hF2_km, hF1_km, hE_km, hEs_km, d_f, d_a, d_h
    REAL*4 foF2_MHz, foF1_MHz, foE_MHz, foEs_MHz
    REAL*4 MUF_1F2_MHz(1:10), MUF_1F1_MHz(1:10)
    REAL*4 MUF_1E_MHz(1:10), MUF_1Es_MHz(1:10)
    REAL*4 MUF_2E_MHz(1:10), MUF_2Es_MHz(1:10)
    REAL*4 CTF_E_MHz, CTF_Es_MHz
    REAL*4 aF2_dg(1:10), aF1_dg(1:10), a1E_dg(1:10), a1Es_dg(1:10)
    REAL*4 a2E_dg(1:10), a2Es_dg(1:10)
    REAL*4 kF, DUM_1, DUM_2, k_VALUE
    REAL*4 fMHz_km_hr_bin, adg_km_hr_bin, hkm_km_hr_bin, M_H
    REAL*4 N_km_hr_F2, N_km_hr_F1, N_km_hr_1E, N_km_hr_1Es, N_km_hr_2E
    REAL*4 N_km_hr_2Es, fMHz_km_bin, adg_km_bin, hkm_km_bin
    REAL*4 N_km_F2, N_km_F1, N_km_1E, N_km_1Es, N_km_2E
    REAL*4 N_km_2Es, N_km_hr, N_km, E_cut_MHz
    REAL*4 N_km_hr_cutE, N_km_hr_cutEs, N_km_cutE, N_km_cutEs
    REAL*4 fMHz_low, fMHz_hgh, adg_low, adg_hgh, hkm_low, hkm_hgh
    REAL*4 f_limit, f_hr_bin, f_bin

    INTEGER*4 i_DAY, i_HOUR, i_DST, N_DST, N_FRQ, N_ANG, N_HGT, ONE
    INTEGER*4 N_DISP

    LOGICAL*1 F2_flag(1:10), F1_flag(1:10), E_flag(1:10,1:2)
    LOGICAL*1 LINK_flag(1:10), Es_flag(1:10,1:2), Es_layer_flag
    LOGICAL*1 E_cut_flag, Es_cut_flag, MONTHLY_flag

    REAL*4 foF2, fxF2, fzF2, M3000F2, hF2, hpf2, foF1, fxF1,-
```

```
         M3000F1, hF1, hF, foE, foE2, hE, hE2, foEs,-
         fxEs, fbEs, fEs, hEs, foF1d5, fmin, M3000F1d5, hf1d5,-
         foI, fxI, fmI, I2000, II, Ixxx

      CHARACTER*20 LNK_file

" ******************************************************************
" Define common blocks

      COMMON/IONSNP/ foF2(31,24), M3000F2(31,24), hF2(31,24), foF1(31,24),-
              M3000F1(31,24), hF1(31,24), hF(31,24), foE(31,24),-
          hE(31,24), foEs(31,24), fbEs(31,24), fEs(31,24),-
          hEs(31,24), fmin(31,24), fxI(31,24)

      COMMON /LIMIT/ fMHz_low, fMHz_hgh, adg_low, adg_hgh, hkm_low, hkm_hgh,-
          N_FRQ, N_ANG, N_HGT, LNK_file, d_f, d_a, d_h, -
          D_km(1:10), N_DST, N_DISP

      COMMON /FRQBN/ fMHz_km_hr_bin(1:10,1:24,0:61), fMHz_km_bin(1:10,0:61), -
          f_limit(1:12,1:2), f_hr_bin(1:10,1:24,1:12), -
          f_bin(1:10,1:12)

      COMMON /ANGBN/ adg_km_hr_bin(1:10,1:24,0:61), adg_km_bin(1:10,0:61), -
          ANG_km_hr_frq(1:10,1:24,0:61,1:2)

      COMMON /HGTBN/ hkm_km_hr_bin(1:10,1:24,0:61), hkm_km_bin(1:10,0:61)

      COMMON /COUNT/ N_km_hr_F2(1:10,1:24), N_km_hr_F1(1:10,1:24), -
              N_km_hr_1E(1:10,1:24), N_km_hr_1Es(1:10,1:24), -
              N_km_hr_2E(1:10,1:24), N_km_hr_2Es(1:10,1:24), -
          N_km_F2(1:10), N_km_F1(1:10), N_km_1E(1:10), -
          N_km_1Es(1:10), N_km_2E(1:10), N_km_2Es(1:10), -
          N_km_hr_cutE(1:10,1:24), N_km_cutE(1:10), -
          N_km_hr_cutEs(1:10,1:24), N_km_cutEs(1:10), -
          N_km_hr(1:10,1:24), N_km(1:10)

" ******************************************************************

      DATA Re_km/6370.0/

" ******************************************************************
" ******************************************************************
" Compute constants

      S_3000 = SIN( 3000.0 / ( 2.0 * 6370.0 ) )
      C_3000 = COS( 3000.0 / ( 2.0 * 6370.0 ) )
      pi = 4.0 * ATAN( 1.0 )
```

```
      rddg = 180.0 / pi
      dgrd = pi / 180.0

      MUF_1F2_MHz = 0.0
      MUF_1F1_MHz = 0.0
      MUF_1E_MHz = 0.0
      MUF_2E_MHz = 0.0
      MUF_1Es_MHz = 0.0
      MUF_2Es_MHz = 0.0
      CTF_E_MHz = 0.0
      CTF_Es_MHz = 0.0
      foF2_MHz = 0.0
      foF1_MHz = 0.0
      foE_MHz = 0.0
      foEs_MHz = 0.0
      hF2_km = 0.0
      hF1_km = 0.0
      hE_km = 0.0
      hEs_km = 0.0

      h_LINK_km = 0.0
      f_LINK_MHz = 0.0
      a_LINK_dg = 0.0

"  Determine the appropriate oblique transmission frequency for the F2 layer
"  at each path length.

      F2_flag = .FALSE.

      IF ( foF2(i_DAY,i_HOUR) .GT. 0.0 ) THEN

          foF2_MHz = foF2(i_DAY,i_HOUR)
          foF2(i_DAY,i_HOUR) = -1.0

        IF ( M3000F2(i_DAY,i_HOUR) .GT. 0.0 ) THEN
          MUF_fctr = M3000F2(i_DAY,i_HOUR)
          M3000F2(i_DAY,i_HOUR) = -1.0
            DUM_1 = MUF_fctr / k_VALUE( 3000.0 )
            DUM_1 = SQRT( DUM_1**2 - 1 )
            hF2_km = Re_km * ( S_3000 / DUM_1 + C_3000 - 1.0 )
        ELSE IF ( hF2(i_DAY,i_HOUR) .GT. 0.0 ) THEN
              hF2_km = hF2(i_DAY,i_HOUR)
              hF2(i_DAY,i_HOUR) = -1.0
          ELSE
            hF2_km = 325.0
          END IF
```

```
" Determine the appropriate transmission frequency for each path length.

      DO i_DST = 1, N_DST

" Determine the included angle for the current path length.

        theta_rd = D_km(i_DST) / Re_km

" Compute the incidence angle for a curved earth.

        DUM_1 = SIN( theta_rd / 2.0 )
        DUM_2 = 1 + hF2_km / Re_km - COS( theta_rd / 2.0 )

        IF ( DUM_2 .LT. 1.0 ) THEN

          IF ( 1.0e38 * DUM_2 .GT. DUM_1 ) THEN
            phi_rd = ATAN2( DUM_1, DUM_2 )
          ELSE
            phi_rd = pi / 2.0
          END IF

        ELSE

          phi_rd = ATAN2( DUM_1, DUM_2 )

        END IF

" Compute the "secant corrected" factor k.

        Kf = k_VALUE( D_km(i_DST) )

" Compute the maximum usable frequency for the F2 layer for the current
" path length.

        MUF_1F2_MHz(i_DST) = Kf * foF2_MHz / COS( phi_rd )

" Compute the appropriate elevation angle for the F2 ray at the current
" value of path length.

          R_km = Re_km + hF2_km
          DUM_1 = 2.0 * Re_km * R_km
        DUM_1 = DUM_1 * COS( D_km(i_DST) / ( 2.0 * Re_km ) )
        DUM_1 = SQRT( R_km**2 + Re_km**2 - DUM_1 )
        DUM_2 = Re_km**2 + DUM_1**2 - R_km**2
        DUM_2 = DUM_2 / ( 2.0 * Re_km * DUM_1 )
          DUM_2 = ACOS( DUM_2 ) - pi / 2.0
        aF2_dg(i_DST) = rddg * DUM_2
```

```
      IF ( aF2_dg(i_DST) .GE. 0.0 ) F2_flag(i_DST) = .TRUE.

     END DO

   END IF

" Determine the appropriate oblique transmission frequency for the F1 layer
" at each path length.

   F1_flag = .FALSE.

   IF ( foF1(i_DAY,i_HOUR) .GT. 0.0 ) THEN

     foF1_MHz = foF1(i_DAY,i_HOUR)
     foF1(i_DAY,i_HOUR) = -1.0

     IF ( M3000F1(i_DAY,i_HOUR) .GT. 0.0 ) THEN
       MUF_fctr = M3000F1(i_DAY,i_HOUR)
       M3000F1(i_DAY,i_HOUR) = -1.0
       DUM_1 = MUF_fctr / k_VALUE( 3000.0 )
         DUM_1 = SQRT( DUM_1**2 - 1 )
         DUM_2 = S_3000 / DUM_1 + C_3000 - 1.0
         hF1_km = Re_km * ( DUM_2 )
     ELSE IF ( hF1(i_DAY,i_HOUR) .GT. 0.0 ) THEN
           hF1_km = hF1(i_DAY,i_HOUR)
           hF1(i_DAY,i_HOUR) = -1.0
     ELSE IF ( hF(i_DAY,i_HOUR) .GT. 0.0 ) THEN
           hF1_km = hF(i_DAY,i_HOUR)
           hF(i_DAY,i_HOUR) = -1.0
       ELSE
         hF1_km = 200.0
       END IF

     DO i_DST = 1, N_DST

"        WRITE(6,*) 'F1 i_DST:  ', i_DST

" Determine the included angle for the current path length.

       theta_rd = D_km(i_DST) / Re_km

" Compute the incidence angle for a curved earth.

         DUM_1 = SIN( theta_rd / 2.0 )
         DUM_2 = 1 + hF1_km / Re_km
         DUM_2 = DUM_2 - COS( theta_rd / 2.0 )
```

```
      IF ( DUM_2 .LT. 1.0 ) THEN

        IF ( 1.0e38 * DUM_2 .GT. DUM_1 ) THEN
          phi_rd = ATAN2( DUM_1, DUM_2 )
        ELSE
          phi_rd = pi / 2.0
        END IF

      ELSE

        phi_rd = ATAN2( DUM_1, DUM_2 )

      END IF

" Compute the "secant corrected" factor k.

      Kf = k_VALUE( D_km(i_DST) )

" Compute the maximum usable frequency for the F1 layer.

      MUF_1F1_MHz(i_DST) = Kf * foF1_MHz / COS( phi_rd )

" Compute the appropriate elevation angle for the F1-reflected ray.

        R_km = Re_km + hF1_km
      DUM_1 = 2.0 * Re_km * R_km
      DUM_1 = DUM_1 * COS( D_km(i_DST) / ( 2.0 * Re_km ) )
      DUM_1 = SQRT( R_km**2 + Re_km**2 - DUM_1 )
      DUM_2 = Re_km**2 + DUM_1**2 - R_km**2
      DUM_2 = DUM_2 / ( 2.0 * Re_km * DUM_1 )
        DUM_2 = ACOS( DUM_2 ) - pi / 2.0
      aF1_dg(i_DST) = rddg * DUM_2

      IF ( aF1_dg(i_DST) .GE. 0.0 ) F1_flag(i_DST) = .TRUE.

    END DO

  END IF

" Determine the appropriate oblique transmission frequency for the E layer
" at each path length.

  E_flag = .FALSE.

  IF ( foE(i_DAY,i_HOUR) .GT. 0.0 ) THEN

    foE_MHz = foE(i_DAY,i_HOUR)
```

```
      foE(i_DAY,i_HOUR) = -1.0

      IF ( hE(i_DAY,i_HOUR) .GT. 0.0 ) THEN
      hE_km = hE(i_DAY,i_HOUR)
      hE(i_DAY,i_HOUR) = -1.0
      ELSE
        hE_km = 110.0
      END IF

    DO i_DST = 1, N_DST

"        WRITE(6,*) 'E i_DST:  ', i_DST

" Determine the included angle for the current path length and ONE E-layer
" hop.

      theta_rd = D_km(i_DST) / Re_km

" Compute the incidence angle for a curved earth.

        DUM_1 = SIN( theta_rd / 2.0 )
        DUM_2 = 1 + hE_km / Re_km
        DUM_2 = DUM_2 - COS( theta_rd / 2.0 )
      IF ( DUM_2 .LT. 1.0 ) THEN

        IF ( 1.0e38 * DUM_2 .GT. DUM_1 ) THEN
          phi_rd = ATAN2( DUM_1, DUM_2 )
        ELSE
          phi_rd = pi / 2.0
        END IF

      ELSE

        phi_rd = ATAN2( DUM_1, DUM_2 )

      END IF

" Compute the "secant corrected" factor k.

      Kf = k_VALUE( D_km(i_DST) )

" Compute the maximum usable frequency for the E layer using ONE hop.

      MUF_1E_MHz(i_DST) = Kf * foE_MHz / COS( phi_rd )

" Compute the appropriate elevation angle for the ONE-hop E-reflected ray.
```

```
      R_km = Re_km + hE_km
    DUM_1 = 2.0 * Re_km * R_km
    DUM_1 = DUM_1 * COS( D_km(i_DST) / ( 2.0 * Re_km ) )
    DUM_1 = SQRT( R_km**2 + Re_km**2 - DUM_1 )
    DUM_2 = Re_km**2 + DUM_1**2 - R_km**2
    DUM_2 = DUM_2 / ( 2.0 * Re_km * DUM_1 )
      DUM_2 = ACOS( DUM_2 ) - pi / 2.0
    a1E_dg(i_DST) = rddg * DUM_2

    IF ( a1E_dg(i_DST) .GE. 0.0 ) E_flag(i_DST,1) = .TRUE.

" Determine the included angle for the current path length and TWO E-layer
" hops.

    theta_rd = D_km(i_DST) / ( 2.0 * Re_km )

" Compute the incidence angle for a curved earth.

      DUM_1 = SIN( theta_rd / 2.0 )
      DUM_2 = 1 + hE_km / Re_km
      DUM_2 = DUM_2 - COS( theta_rd / 2.0 )
    IF ( DUM_2 .LT. 1.0 ) THEN

      IF ( 1.0e38 * DUM_2 .GT. DUM_1 ) THEN
        phi_rd = ATAN2( DUM_1, DUM_2 )
      ELSE
        phi_rd = pi / 2.0
      END IF

    ELSE

      phi_rd = ATAN2( DUM_1, DUM_2 )

    END IF

" Compute the "secant corrected" factor k.

    Kf = k_VALUE( D_km(i_DST) / 2.0 )

" Compute the maximum usable frequency for the E layer for TWO hops.

    MUF_2E_MHz(i_DST) = Kf * foE_MHz / COS( phi_rd )

" Compute the appropriate elevation angle for the TWO-hop E-reflected ray.

      R_km = Re_km + hE_km
    DUM_1 = 2.0 * Re_km * R_km
```

```
        DUM_1 = DUM_1 * COS( D_km(i_DST) / ( 4.0 * Re_km ) )
        DUM_1 = SQRT( R_km**2 + Re_km**2 - DUM_1 )
        DUM_2 = Re_km**2 + DUM_1**2 - R_km**2
        DUM_2 = DUM_2 / ( 2.0 * Re_km * DUM_1 )
          DUM_2 = ACOS( DUM_2 ) - pi / 2.0
        a2E_dg(i_DST) = rddg * DUM_2

        IF ( a2E_dg(i_DST) .GE. 0.0 ) E_flag(i_DST,2) = .TRUE.

      END DO

    END IF

" Determine the appropriate oblique transmission frequency for the Es layer
" at each path length.

    Es_flag = .FALSE.

    IF ( foEs(i_DAY,i_HOUR) .GT. 0.0 .AND. Es_layer_flag ) THEN

      foEs_MHz = foEs(i_DAY,i_HOUR)
      foEs(i_DAY,i_HOUR) = -1.0

      IF ( hEs(i_DAY,i_HOUR) .GT. 0.0 ) THEN
        hEs_km = hEs(i_DAY,i_HOUR)
        hEs(i_DAY,i_HOUR) = -1.0
        ELSE
          hEs_km = 120.0
        END IF

      DO i_DST = 1, N_DST

" Determine the included angle for the current path length and ONE E-layer
" hop.

" Determine the included angle for the current path length.

        theta_rd = D_km(i_DST) / Re_km

" Compute the incidence angle for a curved earth.

          DUM_1 = SIN( theta_rd / 2.0 )
          DUM_2 = 1 + hEs_km / Re_km
          DUM_2 = DUM_2 - COS( theta_rd / 2.0 )
        IF ( DUM_2 .LT. 1.0 ) THEN

          IF ( 1.0e38 * DUM_2 .GT. DUM_1 ) THEN
```

```
      phi_rd = ATAN2( DUM_1, DUM_2 )
    ELSE
      phi_rd = pi / 2.0
    END IF

  ELSE

    phi_rd = ATAN2( DUM_1, DUM_2 )

  END IF

" Compute the "secant corrected" factor k for ONE hop.

  Kf = k_VALUE( D_km(i_DST) )

" Compute the maximum usable frequency for the Es layer for ONE hop.

  MUF_1Es_MHz(i_DST) = Kf * foEs_MHz / COS( phi_rd )

" Compute the appropriate elevation angle for the Es-reflected ray

    R_km = Re_km + hEs_km
  DUM_1 = 2.0 * Re_km * R_km
  DUM_1 = DUM_1 * COS( D_km(i_DST) / ( 2.0 * Re_km ) )
  DUM_1 = SQRT( R_km**2 + Re_km**2 - DUM_1 )
  DUM_2 = Re_km**2 + DUM_1**2 - R_km**2
  DUM_2 = DUM_2 / ( 2.0 * Re_km * DUM_1 )
    DUM_2 = ACOS( DUM_2 ) - pi / 2.0
  a1Es_dg(i_DST) = rddg * DUM_2

  IF ( a1Es_dg(i_DST) .GE. 0.0 ) Es_flag(i_DST,1) = .TRUE.

" Determine the included angle for the current path length and TWO E-layer
" hops.

" Determine the included angle for the current path length.

  theta_rd = D_km(i_DST) / ( 2.0 * Re_km )

" Compute the incidence angle for a curved earth.

    DUM_1 = SIN( theta_rd / 2.0 )
    DUM_2 = 1 + hEs_km / Re_km
    DUM_2 = DUM_2 - COS( theta_rd / 2.0 )
  IF ( DUM_2 .LT. 1.0 ) THEN

    IF ( 1.0e38 * DUM_2 .GT. DUM_1 ) THEN
```

```
      phi_rd = ATAN2( DUM_1, DUM_2 )
    ELSE
      phi_rd = pi / 2.0
    END IF

  ELSE

    phi_rd = ATAN2( DUM_1, DUM_2 )

  END IF

" Compute the "secant corrected" factor k for TWO hops.

  Kf = k_VALUE( D_km(i_DST) / 2.0 )

" Compute the maximum usable frequency for the Es layer for TWO hops.

  MUF_2Es_MHz(i_DST) = Kf * foEs_MHz / COS( phi_rd )

" Compute the appropriate elevation angle for the Es-reflected ray for
" TWO-hop HF propagation.

     R_km = Re_km + hEs_km
  DUM_1 = 2.0 * Re_km * R_km
  DUM_1 = DUM_1 * COS( D_km(i_DST) / ( 4.0 * Re_km ) )
  DUM_1 = SQRT( R_km**2 + Re_km**2 - DUM_1 )
  DUM_2 = Re_km**2 + DUM_1**2 - R_km**2
  DUM_2 = DUM_2 / ( 2.0 * Re_km * DUM_1 )
     DUM_2 = ACOS( DUM_2 ) - pi / 2.0
  a2Es_dg(i_DST) = rddg * DUM_2

  IF ( a2Es_dg(i_DST) .GE. 0.0 ) Es_flag(i_DST,2) = .TRUE.

 END DO

END IF

" Determine the MUF, the virtual height, and the elevation angle for
" each HF link range and increment appropriate bins.

DO i_DST = 1, N_DST

" Increment the number of hours used in each distribution

  N_km(i_DST) = N_km(i_DST) + 1.0
  N_km_hr(i_DST,i_HOUR) = N_km_hr(i_DST,i_HOUR) + 1.0
```

```
" First, determine HF link propagation if it were provided by the F2 layer
" via ONE hop.

      IF ( F2_flag(i_DST) ) THEN

         h_LINK_km = hF2_km
         f_LINK_MHz = MUF_1F2_MHz(i_DST)
         a_LINK_dg = aF2_dg(i_DST)
         N_km_hr_F2(i_DST,i_HOUR) = N_km_hr_F2(i_DST,i_HOUR) + 1.0
         N_km_F2(i_DST) = N_km_F2(i_DST) + 1.0

      END IF

" Check to see if the F1 layer supercedes the F2 layer and supports the
" specified propagation range via ONE hop.

      IF ( F1_flag(i_DST) .AND. -
           MUF_1F1_MHz(i_DST) .GT. f_LINK_MHz ) THEN

         h_LINK_km = hF1_km
         f_LINK_MHz = MUF_1F1_MHz(i_DST)
         a_LINK_dg = aF1_dg(i_DST)

        IF ( F2_flag(i_DST) ) THEN
           N_km_hr_F2(i_DST,i_HOUR) = N_km_hr_F2(i_DST,i_HOUR) - 1.0
           N_km_F2(i_DST) = N_km_F2(i_DST) - 1.0
           F2_flag(i_DST) = .FALSE.
         END IF
         N_km_hr_F1(i_DST,i_HOUR) = N_km_hr_F1(i_DST,i_HOUR) + 1.0
         N_km_F1(i_DST) = N_km_F1(i_DST) + 1.0

      ELSE IF ( F1_flag(i_DST) .AND. -
                MUF_1F1_MHz(i_DST) .LE. f_LINK_MHz ) THEN

          F1_flag(i_DST) = .FALSE.

        END IF

" Check to see if the E layer supercedes the F2 and F1 layers and supports
" the specified propagation range via ONE hop.

      IF ( E_flag(i_DST,1) .AND. -
           MUF_1E_MHz(i_DST) .GT. f_LINK_MHz ) THEN

         h_LINK_km = hE_km
         f_LINK_MHz = MUF_1E_MHz(i_DST)
         a_LINK_dg = a1E_dg(i_DST)
```

```
    IF ( F2_flag(i_DST) ) THEN
        N_km_hr_F2(i_DST,i_HOUR) = N_km_hr_F2(i_DST,i_HOUR) - 1.0
        N_km_F2(i_DST) = N_km_F2(i_DST) - 1.0
        F2_flag(i_DST) = .FALSE.
      END IF
    IF ( F1_flag(i_DST) ) THEN
        N_km_hr_F1(i_DST,i_HOUR) = N_km_hr_F1(i_DST,i_HOUR) - 1.0
        N_km_F1(i_DST) = N_km_F1(i_DST) - 1.0
        F1_flag(i_DST) = .FALSE.
      END IF
      N_km_hr_1E(i_DST,i_HOUR) = N_km_hr_1E(i_DST,i_HOUR) + 1.0
      N_km_1E(i_DST) = N_km_1E(i_DST) + 1.0

  ELSE IF ( E_flag(i_DST,1) .AND. -
            MUF_1E_MHz(i_DST) .LE. f_LINK_MHz ) THEN

      E_flag(i_DST,1) = .FALSE.

  END IF

" Check to see if the E layer supercedes the F2 and F1 layers and supports
" the specified propagation range via TWO hops.

   IF ( E_flag(i_DST,2) .AND. -
        MUF_2E_MHz(i_DST) .GT. f_LINK_MHz ) THEN

      h_LINK_km = hE_km
      f_LINK_MHz = MUF_2E_MHz(i_DST)
      a_LINK_dg = a2E_dg(i_DST)

    IF ( F2_flag(i_DST) ) THEN
        N_km_hr_F2(i_DST,i_HOUR) = N_km_hr_F2(i_DST,i_HOUR) - 1.0
        N_km_F2(i_DST) = N_km_F2(i_DST) - 1.0
        F2_flag(i_DST) = .FALSE.
      END IF
    IF ( F1_flag(i_DST) ) THEN
        N_km_hr_F1(i_DST,i_HOUR) = N_km_hr_F1(i_DST,i_HOUR) - 1.0
        N_km_F1(i_DST) = N_km_F1(i_DST) - 1.0
        F1_flag(i_DST) = .FALSE.
      END IF
    IF ( E_flag(i_DST,1) ) THEN
        N_km_hr_1E(i_DST,i_HOUR) = N_km_hr_1E(i_DST,i_HOUR) - 1.0
        N_km_1E(i_DST) = N_km_1E(i_DST) - 1.0
        E_flag(i_DST,1) = .FALSE.
      END IF
      N_km_hr_2E(i_DST,i_HOUR) = N_km_hr_2E(i_DST,i_HOUR) + 1.0
```

```
        N_km_2E(i_DST) = N_km_2E(i_DST) + 1.0

     ELSE IF ( E_flag(i_DST,2) .AND. -
               MUF_2E_MHz(i_DST) .LE. f_LINK_MHz ) THEN

        E_flag(i_DST,2) = .FALSE.

     END IF

"  Check to see if the Es layer supercedes the F2, F1, and E layers and
"  supports the specified propagation range via ONE hop.

     IF ( Es_flag(i_DST,1) .AND. MUF_1Es_MHz(i_DST) -
        .GT. f_LINK_MHz .AND. Es_layer_flag ) THEN

        h_LINK_km = hEs_km
        f_LINK_MHz = MUF_1Es_MHz(i_DST)
        a_LINK_dg = a1Es_dg(i_DST)

      IF ( F2_flag(i_DST) ) THEN
         N_km_hr_F2(i_DST,i_HOUR) = N_km_hr_F2(i_DST,i_HOUR) - 1.0
         N_km_F2(i_DST) = N_km_F2(i_DST) - 1.0
         F2_flag(i_DST) = .FALSE.
        END IF
      IF ( F1_flag(i_DST) ) THEN
         N_km_hr_F1(i_DST,i_HOUR) = N_km_hr_F1(i_DST,i_HOUR) - 1.0
         N_km_F1(i_DST) = N_km_F1(i_DST) - 1.0
         F1_flag(i_DST) = .FALSE.
        END IF
      IF ( E_flag(i_DST,1) ) THEN
         N_km_hr_1E(i_DST,i_HOUR) = N_km_hr_1E(i_DST,i_HOUR) - 1.0
         N_km_1E(i_DST) = N_km_1E(i_DST) - 1.0
         E_flag(i_DST,1) = .FALSE.
        END IF
      IF ( E_flag(i_DST,2) ) THEN
         N_km_hr_2E(i_DST,i_HOUR) = N_km_hr_2E(i_DST,i_HOUR) - 1.0
         N_km_2E(i_DST) = N_km_2E(i_DST) - 1.0
         E_flag(i_DST,2) = .FALSE.
        END IF
        N_km_hr_1Es(i_DST,i_HOUR) = N_km_hr_1Es(i_DST,i_HOUR) + 1.0
        N_km_1Es(i_DST) = N_km_1Es(i_DST) + 1.0

     ELSE IF ( Es_flag(i_DST,1) .AND. -
               MUF_1Es_MHz(i_DST) .LE. f_LINK_MHz ) THEN

        Es_flag(i_DST,1) = .FALSE.
```

```
END IF

" Check to see if the Es layer supercedes the F2, F1, and E layers and
" supports the specified propagation range via TWO hops.

IF ( Es_flag(i_DST,2) .AND. MUF_2Es_MHz(i_DST) .GT.-
   f_LINK_MHz .AND. Es_layer_flag ) THEN

      h_LINK_km = hEs_km
      f_LINK_MHz = MUF_2Es_MHz(i_DST)
      a_LINK_dg = a2Es_dg(i_DST)

   IF ( F2_flag(i_DST) ) THEN
        N_km_hr_F2(i_DST,i_HOUR) = N_km_hr_F2(i_DST,i_HOUR) - 1.0
        N_km_F2(i_DST) = N_km_F2(i_DST) - 1.0
        F2_flag(i_DST) = .FALSE.
      END IF
   IF ( F1_flag(i_DST) ) THEN
        N_km_hr_F1(i_DST,i_HOUR) = N_km_hr_F1(i_DST,i_HOUR) - 1.0
        N_km_F1(i_DST) = N_km_F1(i_DST) - 1.0
        F1_flag(i_DST) = .FALSE.
      END IF
   IF ( E_flag(i_DST,1) ) THEN
        N_km_hr_1E(i_DST,i_HOUR) = N_km_hr_1E(i_DST,i_HOUR) - 1.0
        N_km_1E(i_DST) = N_km_1E(i_DST) - 1.0
        E_flag(i_DST,1) = .FALSE.
      END IF
   IF ( E_flag(i_DST,2) ) THEN
        N_km_hr_2E(i_DST,i_HOUR) = N_km_hr_2E(i_DST,i_HOUR) - 1.0
        N_km_2E(i_DST) = N_km_2E(i_DST) - 1.0
        E_flag(i_DST,2) = .FALSE.
      END IF
   IF ( Es_flag(i_DST,1) ) THEN
        N_km_hr_1Es(i_DST,i_HOUR) = N_km_hr_1Es(i_DST,i_HOUR) - 1.0
        N_km_1Es(i_DST) = N_km_1Es(i_DST) - 1.0
        Es_flag(i_DST,1) = .FALSE.
      END IF
      N_km_hr_2Es(i_DST,i_HOUR) = N_km_hr_2Es(i_DST,i_HOUR) + 1.0
      N_km_2Es(i_DST) = N_km_2Es(i_DST) + 1.0

ELSE IF ( Es_flag(i_DST,2) .AND. -
           MUF_2Es_MHz(i_DST) .LE. f_LINK_MHz ) THEN

      Es_flag(i_DST,2) = .FALSE.

END IF
```

```
" If an F-layer HF link is determined, compute E- and Es-layer
" cut-off frequencies to determine if foreshortening occurs.

" Compute the E-layer cut-off frequency.

     IF ( foE_MHz .GT. 0.0 .AND. hE_km .GT. 0.0 ) THEN

       R_km = Re_km + hE_km
       alpha_rd = pi / 2.0 + dgrd * a_LINK_dg
       DUM_1 = Re_km * COS( alpha_rd )
       DUM_2 = SQRT( R_km**2 - ( SIN( alpha_rd ) * Re_km )**2 )
         dkm = DUM_1 + DUM_2

       DUM_1 = R_km**2 + Re_km**2 - dkm**2
         DUM_2 = 2.0 * R_km * Re_km
       theta_rd = 2.0 * ACOS( DUM_1 / DUM_2 )

         D_E_km = Re_km * theta_rd

" Compute the incidence angle for a curved earth.

         DUM_1 = SIN( theta_rd / 2.0 )
       DUM_2 = 1 + hE_km / Re_km - COS( theta_rd / 2.0 )
       IF ( DUM_2 .LT. 1.0 ) THEN

         IF ( 1.0e38 * DUM_2 .GT. DUM_1 ) THEN
           phi_cutE_rd = ATAN2( DUM_1, DUM_2 )
         ELSE
           phi_cutE_rd = pi / 2.0
         END IF

       ELSE

         phi_cutE_rd = ATAN2( DUM_1, DUM_2 )

       END IF

" Compute the "secant corrected" factor k.

         Kf = k_VALUE( D_E_km )

" Compute the maximum usable frequency for the E-layer cut-off frequency.

       CTF_E_MHz = Kf * foE_MHz / COS( phi_cutE_rd )

       END IF
```

```
" Compute the Es-layer cut-off frequency.

      IF ( foEs_MHz .GT. 0.0 .AND. hEs_km .GT. 0.0 ) THEN

      R_km = Re_km + hEs_km
      alpha_rd = pi / 2.0 + dgrd * a_LINK_dg
      DUM_1 = Re_km * COS( alpha_rd )
      DUM_2 = SQRT( R_km**2 - ( SIN( alpha_rd ) * Re_km )**2 )
        dkm = DUM_1 + DUM_2

      DUM_1 = R_km**2 + Re_km**2 - dkm**2
        DUM_2 = 2.0 * R_km * Re_km
      theta_rd = 2.0 * ACOS( DUM_1 / DUM_2 )

        D_Es_km = Re_km * theta_rd

" Compute the incidence angle for a curved earth.

        DUM_1 = SIN( theta_rd / 2.0 )
      DUM_2 = 1 + hEs_km / Re_km - COS( theta_rd / 2.0 )
      IF ( DUM_2 .LT. 1.0 ) THEN

        IF ( 1.0e38 * DUM_2 .GT. DUM_1 ) THEN
          phi_cutEs_rd = ATAN2( DUM_1, DUM_2 )
        ELSE
          phi_cutEs_rd = pi / 2.0
        END IF

      ELSE

        phi_cutEs_rd = ATAN2( DUM_1, DUM_2 )

      END IF

" Compute the "secant corrected" factor k.

        Kf = k_VALUE( D_Es_km )

" Compute the maximum usable frequency for the Es layer cut-off frequency.

      CTF_Es_MHz = Kf * foEs_MHz / COS( phi_cutEs_rd )

    END IF

" Pick the larger of the two E and Es cutoff frequencies.  At present, the
" one-hop modes should always exceed the cut-off frequencies.  This result
" will change when multihop F-layer reflections are included.
```

```
      E_cut_flag = .FALSE.
      Es_cut_flag = .FALSE.

        IF ( ( F2_flag(i_DST) .OR. F1_flag(i_DST) ) .AND. -
           ( CTF_E_MHz .GT. f_LINK_MHz -
           .OR. CTF_Es_MHz .GT. f_LINK_MHz ) ) THEN
        IF ( CTF_E_MHz .GT. CTF_Es_MHz ) THEN
          E_cut_MHz = CTF_E_MHz
          E_cut_flag = .TRUE.
          Es_cut_flag = .FALSE.
        ELSE
          E_cut_MHz = CTF_Es_MHz
          Es_cut_flag = .TRUE.
          E_cut_flag = .FALSE.
        END IF
      END IF

" Determine if an HF link exists at the current distance independent of
" E- or Es-layer cutoff.

        LINK_flag(i_DST) = .FALSE.

      IF ( E_flag(i_DST,1) .OR. E_flag(i_DST,2) -
         .OR. Es_flag(i_DST,1) .OR. Es_flag(i_DST,2) -
         .OR. F2_flag(i_DST) .OR. F1_flag(i_DST) ) THEN

        LINK_flag(i_DST) = .TRUE.

" Update all HF link probability bins

          CALL binFIL3( i_DST, i_HOUR, f_LINK_MHz, fMHz_low, fMHz_hgh, -
                        fMHz_km_hr_bin, fMHz_km_bin, N_FRQ )

          CALL binFIL3( i_DST, i_HOUR, a_LINK_dg, adg_low, adg_hgh, -
                        adg_km_hr_bin, adg_km_bin, N_ANG )

          CALL binFIL3( i_DST, i_HOUR, h_LINK_km, hkm_low, hkm_hgh, -
                 hkm_km_hr_bin, hkm_km_bin, N_HGT )

" Update frequency-conditional take-off angle mean bins.

        i_FRQ = INT( ( f_LINK_MHz - fMHz_low ) / d_f ) + 1

        IF ( f_LINK_MHz .LE. fMHz_low ) THEN

          ANG_km_hr_frq(i_DST,i_HOUR,0,1) = -
```

```
                ANG_km_hr_frq(i_DST,i_HOUR,0,1) -
                + 1.0
  ANG_km_hr_frq(i_DST,i_HOUR,0,2) = -
                ANG_km_hr_frq(i_DST,i_HOUR,0,2) -
                + a_LINK_dg

ELSE IF ( f_LINK_MHz .GT. fMHz_hgh ) THEN

    ANG_km_hr_frq(i_DST,i_HOUR,N_FRQ+1,1) = -
                ANG_km_hr_frq(i_DST,i_HOUR,N_FRQ+1,1) -
                + 1.0
    ANG_km_hr_frq(i_DST,i_HOUR,N_FRQ+1,2) = -
                ANG_km_hr_frq(i_DST,i_HOUR,N_FRQ+1,2) -
                + a_LINK_dg

ELSE

  ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,1) = -
                ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,1) -
                + 1.0
  ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,2) = -
                ANG_km_hr_frq(i_DST,i_HOUR,i_FRQ,2) -
                + a_LINK_dg

END IF

" If output is not for "*.LNK" files, that is, MONTHLY_flag = .FALSE.,
" then increment appropriate bin values in frequency bins.

IF ( .NOT. MONTHLY_flag ) THEN

  DO i_DISP = 1, N_DISP

    IF ( f_LINK_MHz .GT. f_limit(i_DISP,1) -
       .AND. f_LINK_MHz .LE. f_limit(i_DISP,2) ) THEN

      f_hr_bin(i_DST,i_HOUR,i_DISP) = -
                f_hr_bin(i_DST,i_HOUR,i_DISP) + 1.0

      f_bin(i_DST,i_DISP) = f_bin(i_DST,i_DISP) + 1.0

    END IF

  END DO

END IF
```

```
" Determine whether or not E or Es-layer cutoff occurred and increment the
" appropriate bins.

        IF ( E_cut_MHz .GT. f_LINK_MHz ) THEN

          IF ( E_cut_flag ) THEN
            N_km_hr_cutE(i_DST,i_HOUR) = -
                      N_km_hr_cutE(i_DST,i_HOUR) + 1.0
            N_km_cutE(i_DST) = N_km_cutE(i_DST) + 1.0
          END IF

          IF ( Es_cut_flag ) THEN
            N_km_hr_cutEs(i_DST,i_HOUR) = -
                      N_km_hr_cutEs(i_DST,i_HOUR) + 1.0
            N_km_cutEs(i_DST) = N_km_cutEs(i_DST) + 1.0
          END IF

        END IF

      END IF

" Output statements are used to chaeck HFLINKS calculations. Normally,
" these lines are not compiled.

"       IF ( ( i_HOUR .EQ. 1 .OR. i_HOUR .EQ. 24 ) .AND. D_km(i_DST) -
"          .GT. 1600.0 ) THEN
"         WRITE(5,*) '*********************************************'
"         WRITE(5,*) 'D_km: ', D_km(i_DST)
"         WRITE(5,*) 'd_f: ', d_f, ' d_a: ', d_a, ' d_h: ', d_h
"         WRITE(5,*) 'foF2_MHz: ', foF2_MHz,' hF2_km:  ',hF2_km
"         WRITE(5,*) 'MUF_1F2_MHz: ', MUF_1F2_MHz(i_DST)
"         WRITE(5,*) 'foF1_MHz: ', foF1_MHz,' hF1_km:  ',hF1_km
"         WRITE(5,*) 'MUF_1F1_MHz: ', MUF_1F1_MHz(i_DST)
"         WRITE(5,*) 'foE_MHz: ', foE_MHz,' hE_km:  ',hE_km
"         WRITE(5,*) 'MUF_1E_MHz: ', MUF_1E_MHz(i_DST)
"         WRITE(5,*) 'MUF_2E_MHz: ', MUF_2E_MHz(i_DST)
"         WRITE(5,*) 'foEs_MHz: ', foEs_MHz,' hEs_km:  ',hEs_km
"         WRITE(5,*) 'MUF_1Es_MHz: ', MUF_1Es_MHz(i_DST)
"         WRITE(5,*) 'MUF_2Es_MHz: ', MUF_2Es_MHz(i_DST)
"         WRITE(5,*) 'Re_km:  ',Re_km, 'R_km:  ', R_km
"         WRITE(5,*) 'alpha_dg:  ',rddg*alpha_rd, 'dkm:  ', dkm
"         WRITE(5,*) 'CTF_E_MHz: ', CTF_E_MHz,' D_E_km:  ',D_E_km
"         WRITE(5,*) 'CTF_Es_MHz: ', CTF_Es_MHz,' D_Es_km:  ',D_Es_km
"         WRITE(5,*) 'F2_flag: ', F2_flag(i_DST)
"         WRITE(5,*) 'phi_cutE_dg: ', rddg * phi_cutE_rd
"         WRITE(5,*) 'phi_cutEs_dg: ', rddg * phi_cutEs_rd
"         WRITE(5,*) i_DAY, i_HOUR, 'f_LINK_MHz: ', f_LINK_MHz
```

```
"        WRITE(5,*) 'a_LINK_dg: ', a_LINK_dg
"        WRITE(5,*) 'h_LINK_km: ', h_LINK_km
"        WRITE(5,*) 'LINK_flag: ', LINK_flag(i_DST)
"        WRITE(5,*) "Type <1> to continue"
"        READ(5,*) ONE
"      END IF

    END DO

    RETURN

    END


"                   SUBROUTINE k_VALUE
"
" Purpose:  To compute the 'secant-corrected' effect of a curved ionosphere


    REAL*4 FUNCTION k_VALUE( D )

    REAL*4 D, D_smp(17), k_smp(17), m_k, b_k

    DATA D_smp/0.0,231.9,318.8,376.8,492.8,608.7,782.6,985.5,1246.4,-
            2800.0,3014.5,3205.8,3373.9,3536.2,3687.0,3884.1,-
            4000.0/
    DATA k_smp/1.0,1.0,1.0007,1.0014,1.0035,1.0058,1.0111,1.0188,-
            1.0294,1.1047,1.1153,1.1259,1.1365,1.1471,1.1612,-
            1.1772,1.1871/

    IF ( D .LT. D_smp(1) ) THEN
      k_VALUE = k_smp(1)
      RETURN
    END IF

    IF ( D .GE. D_smp(17) ) THEN
      k_VALUE = k_smp(17)
      RETURN
    END IF

    DO k = 2, 17

      IF ( D_smp(k-1) .LE. D .AND. D .LT. D_smp(k) ) THEN

        DUM_1 = D_smp(k) - D_smp(k-1)
        m_k = ( k_smp(k) - k_smp(k-1) ) / DUM_1
```

```
        b_k = ( k_smp(k-1) * D_smp(k) - k_smp(k) * D_smp(k-1) ) / DUM_1
        k_VALUE = m_k * D + b_k
        RETURN

      END IF

    END DO

    RETURN

    END
```

```
"                    SUBROUTINE binFIL3
"
" Purpose:  Increment density function bin corresponding to input value

    SUBROUTINE binFIL3( i_1, i_2, Vr, Vr_low, Vr_hgh, bin_3, bin_2, N_bins )

    REAL*4 bin_3(1:10,1:24,0:61)
    REAL*4 bin_2(1:10,0:61)
    REAL*4 Vr, Vr_low, Vr_hgh
    INTEGER*4 N_bins, i_1, i_2

    LOGICAL*1 B_flag

    IF ( Vr .LE. Vr_low ) THEN
      bin_3(i_1,i_2,0) = bin_3(i_1,i_2,0) + 1.0
      bin_2(i_1,0) = bin_2(i_1,0) + 1.0
    ELSE IF ( Vr .GT. Vr_hgh ) THEN
         bin_3(i_1,i_2,N_bins+1) = bin_3(i_1,i_2,N_bins+1) + 1.0
         bin_2(i_1,N_bins+1) = bin_2(i_1,N_bins+1) + 1.0
    ELSE
      i_bin = 1
      B_flag = .FALSE.
        d_Vr = ( Vr_hgh - Vr_low ) / FLOAT( N_bins )
      DO WHILE ( i_bin .LE. N_bins .AND. .NOT. B_flag )
          Vr_min = Vr_low + ( i_bin - 1 ) * d_Vr
        Vr_max = Vr_min + d_Vr
        IF ( Vr .GT. Vr_min .AND. Vr .LE. Vr_max ) THEN
          bin_3(i_1,i_2,i_bin) = bin_3(i_1,i_2,i_bin) + 1.0
          bin_2(i_1,i_bin) = bin_2(i_1,i_bin) + 1.0
          B_flag = .TRUE.
        END IF
```

```
      i_bin = i_bin + 1
    END DO
  END IF

  RETURN

  END


"              SUBROUTINE PARMBIN
"
" Purpose:  Enter parameter values from UAG-23.NEW formatted files into
"        appropriate arrays holding all hourly values for a given month.

  SUBROUTINE PARMBIN( i_DAY, i_HOUR, i_CODE, P_value, C_value, D_value )

  REAL*4 P_value
  INTEGER*4 i_DAY, i_HOUR, i_CODE
  CHARACTER*1 C_value, D_value

  REAL*4 foF2, fxF2, fzF2, M3000F2, hF2, hpf2, foF1, fxF1,-
         M3000F1, hF1, hF, foE, foE2, hE, hE2, foEs,-
         fxEs, fbEs, fEs, hEs, foF1d5, fmin, M3000F1d5, hf1d5,-
         foI, fxI, fmI, I2000, II, Ixxx

"  CHARACTER*1 QfoF2, QfxF2, QfzF2, QM3000F2, QhF2, Qhpf2, QfoF1, QfxF1,-
"             QM3000F1, QhF1, QhF, QfoE, QfoE2, QhE, QhE2, QfoEs,-
"             QfxEs, QfbEs, QfEs, QhEs, QfoF1d5, Qfmin, QM3000F1d5,-
"             Qhf1d5, QfoI, QfxI, QfmI, QI2000, QI, QIxxx

"  CHARACTER*1 DfoF2, DfxF2, DfzF2, DM3000F2, DhF2, Dhpf2, DfoF1, DfxF1,-
"             DM3000F1, DhF1, DhF, DfoE, DfoE2, DhE, DhE2, DfoEs,-
"             DfxEs, DfbEs, DfEs, DhEs, DfoF1d5, Dfmin, DM3000F1d5,-
"             Dhf1d5, DfoI, DfxI, DfmI, DI2000, DI, DIxxx

" ****************************************************************
" Define common blocks

  COMMON/IONSNP/ foF2(31,24), M3000F2(31,24), hF2(31,24), foF1(31,24),-
               M3000F1(31,24), hF1(31,24), hF(31,24), foE(31,24),-
           hE(31,24), foEs(31,24), fbEs(31,24), fEs(31,24),-
           hEs(31,24), fmin(31,24), fxI(31,24)

  IF ( i_CODE .EQ. 1 ) THEN
     foF2(i_DAY,i_HOUR) = P_value
"    QfoF2(i_DAY,i_HOUR) = Q_char
```

```
"      DfoF2(i_DAY,i_HOUR) = D_char
    END IF

"           IF ( i_CODE .EQ. 2 ) THEN
"             fxF2(i_DAY,i_HOUR) = P_value
"             QfxF2(i_DAY,i_HOUR) = Q_char
"             DfxF2(i_DAY,i_HOUR) = D_char
"           END IF

"           IF ( i_CODE .EQ. 3 ) THEN
"             fzF2(i_DAY,i_HOUR) = P_value
"             QfzF2(i_DAY,i_HOUR) = Q_char
"             DfzF2(i_DAY,i_HOUR) = D_char
"           END IF

    IF ( i_CODE .EQ. 4 ) THEN
      M3000F2(i_DAY,i_HOUR) = P_value
"     QM3000F2(i_DAY,i_HOUR) = Q_char
"     DM3000F2(i_DAY,i_HOUR) = D_char
    END IF

    IF ( i_CODE .EQ. 5 ) THEN
      hF2(i_DAY,i_HOUR) = P_value
"     QhF2(i_DAY,i_HOUR) = Q_char
"     DhF2(i_DAY,i_HOUR) = D_char
    END IF

"           IF ( i_CODE .EQ. 6 ) THEN
"             hpF2(i_DAY,i_HOUR) = P_value
"             QhpF2(i_DAY,i_HOUR) = Q_char
"             DhpF2(i_DAY,i_HOUR) = D_char
"           END IF

    IF ( i_CODE .EQ. 7 ) THEN
      foF1(i_DAY,i_HOUR) = P_value
"     QfoF1(i_DAY,i_HOUR) = Q_char
"     DfoF1(i_DAY,i_HOUR) = D_char
    END IF

"           IF ( i_CODE .EQ. 8 ) THEN
"             fxF1(i_DAY,i_HOUR) = P_value
"             QfxF1(i_DAY,i_HOUR) = Q_char
"             DfxF1(i_DAY,i_HOUR) = D_char
"           END IF

    IF ( i_CODE .EQ. 9 ) THEN
      M3000F1(i_DAY,i_HOUR) = P_value
```

```
"       QM3000F1(i_DAY,i_HOUR) = Q_char
"       DM3000F1(i_DAY,i_HOUR) = D_char
    END IF

    IF ( i_CODE .EQ. 10 ) THEN
        hF1(i_DAY,i_HOUR) = P_value
"       QhF1(i_DAY,i_HOUR) = Q_char
"       DhF1(i_DAY,i_HOUR) = D_char
    END IF

    IF ( i_CODE .EQ. 11 ) THEN
        hF(i_DAY,i_HOUR) = P_value
"       QhF(i_DAY,i_HOUR) = Q_char
"       DhF(i_DAY,i_HOUR) = D_char
    END IF

    IF ( i_CODE .EQ. 12 ) THEN
        foE(i_DAY,i_HOUR) = P_value
"       QfoE(i_DAY,i_HOUR) = Q_char
"       DfoE(i_DAY,i_HOUR) = D_char
    END IF

"           IF ( i_CODE .EQ. 13 ) THEN
"             foE2(i_DAY,i_HOUR) = P_value
"             QfoE2(i_DAY,i_HOUR) = Q_char
"             DfoE2(i_DAY,i_HOUR) = D_char
"           END IF

    IF ( i_CODE .EQ. 14 ) THEN
        hE(i_DAY,i_HOUR) = P_value
"       QhE(i_DAY,i_HOUR) = Q_char
"       DhE(i_DAY,i_HOUR) = D_char
    END IF

"           IF ( i_CODE .EQ. 15 ) THEN
"             hE2(i_DAY,i_HOUR) = P_value
"             QhE2(i_DAY,i_HOUR) = Q_char
"             DhE2(i_DAY,i_HOUR) = D_char
"           END IF

    IF ( i_CODE .EQ. 16 ) THEN
        foEs(i_DAY,i_HOUR) = P_value
"       QfoEs(i_DAY,i_HOUR) = Q_char
"       DfoEs(i_DAY,i_HOUR) = D_char
    END IF

"           IF ( i_CODE .EQ. 17 ) THEN
```

```
"            fxEs(i_DAY,i_HOUR) = P_value
"            QfxEs(i_DAY,i_HOUR) = Q_char
"            DfxEs(i_DAY,i_HOUR) = D_char
"          END IF

"          IF ( i_CODE .EQ. 18 ) THEN
"            fbEs(i_DAY,i_HOUR) = P_value
"            QfbEs(i_DAY,i_HOUR) = Q_char
"            DfbEs(i_DAY,i_HOUR) = D_char
"          END IF

      IF ( i_CODE .EQ. 19 ) THEN
        fEs(i_DAY,i_HOUR) = P_value
"       QfEs(i_DAY,i_HOUR) = Q_char
"       DfEs(i_DAY,i_HOUR) = D_char
      END IF

      IF ( i_CODE .EQ. 20 ) THEN
        hEs(i_DAY,i_HOUR) = P_value
"       QhEs(i_DAY,i_HOUR) = Q_char
"       DhEs(i_DAY,i_HOUR) = D_char
      END IF

"          IF ( i_CODE .EQ. 21 ) THEN
"            foF1d5(i_DAY,i_HOUR) = P_value
"            QfoF1d5(i_DAY,i_HOUR) = Q_char
"            DfoF1d5(i_DAY,i_HOUR) = D_char
"          END IF

      IF ( i_CODE .EQ. 22 ) THEN
        fmin(i_DAY,i_HOUR) = P_value
"       Qfmin(i_DAY,i_HOUR) = Q_char
"       Dfmin(i_DAY,i_HOUR) = D_char
      END IF

"          IF ( i_CODE .EQ. 23 ) THEN
"            M3000F1d5(i_DAY,i_HOUR) = P_value
"            QM3000F1d5(i_DAY,i_HOUR) = Q_char
"            DM3000F1d5(i_DAY,i_HOUR) = D_char
"          END IF

"          IF ( i_CODE .EQ. 24 ) THEN
"            hF1d5(i_DAY,i_HOUR) = P_value
"            QhF1d5(i_DAY,i_HOUR) = Q_char
"            DhF1d5(i_DAY,i_HOUR) = D_char
"          END IF
```

```
"           IF ( i_CODE .EQ. 25 ) THEN
"             foI(i_DAY,i_HOUR) = P_value
"             QfoI(i_DAY,i_HOUR) = Q_char
"             DfoI(i_DAY,i_HOUR) = D_char
"           END IF

"           IF ( i_CODE .EQ. 26 ) THEN
"             fxI(i_DAY,i_HOUR) = P_value
"             QfxI(i_DAY,i_HOUR) = Q_char
"             DfxI(i_DAY,i_HOUR) = D_char
"           END IF

"           IF ( i_CODE .EQ. 27 ) THEN
"             fmI(i_DAY,i_HOUR) = P_value
"             QfmI(i_DAY,i_HOUR) = Q_char
"             DfmI(i_DAY,i_HOUR) = D_char
"           END IF

"           IF ( i_CODE .EQ. 28 ) THEN
"             I2000(i_DAY,i_HOUR) = P_value
"             QI2000(i_DAY,i_HOUR) = Q_char
"             DI2000(i_DAY,i_HOUR) = D_char
"           END IF

"           IF ( i_CODE .EQ. 29 ) THEN
"             II(i_DAY,i_HOUR) = P_value
"             QI(i_DAY,i_HOUR) = Q_char
"             DI(i_DAY,i_HOUR) = D_char
"           END IF

"           IF ( i_CODE .EQ. 30 ) THEN
"             Ixxx(i_DAY,i_HOUR) = P_value
"             QIxxx(i_DAY,i_HOUR) = Q_char
"             DIxxx(i_DAY,i_HOUR) = D_char
"           END IF

       RETURN

       END
```

APPENDIX C IONOLINK FREQUENCY DENSITY PLOTS

This appendix contains two types of plots describing frequency availability for oblique HF propagation. This data was derived from UAG-23-formatted ionosonde data measured at Scott Base in Antarctica. The years of 1975 and 1979 were chosen for this analysis. The 1975 year corresponded to low sunspot numbers while 1979 experienced much higher sunspot numbers. Each calender year was divided into two 6-month periods, one for maximum solar zenith angle (minimum sun visibility) from April to September, and the second period for minimum zenith angle (maximum sun visibility) from October through March. Note that the 1975 ionosonde data did not contain F1-, E-, or Es-layer data, only F2-layer values. Since 1975 experienced a low sunspot number on average ($\cong 22$) versus 1979 ($\cong 153$), the lack of data did not present a significant reduction in measurement validity. Critical frequencies for these layers were provided in the 1979 data set. The following table provides a description of the plots as well as an index to locate specific plots.

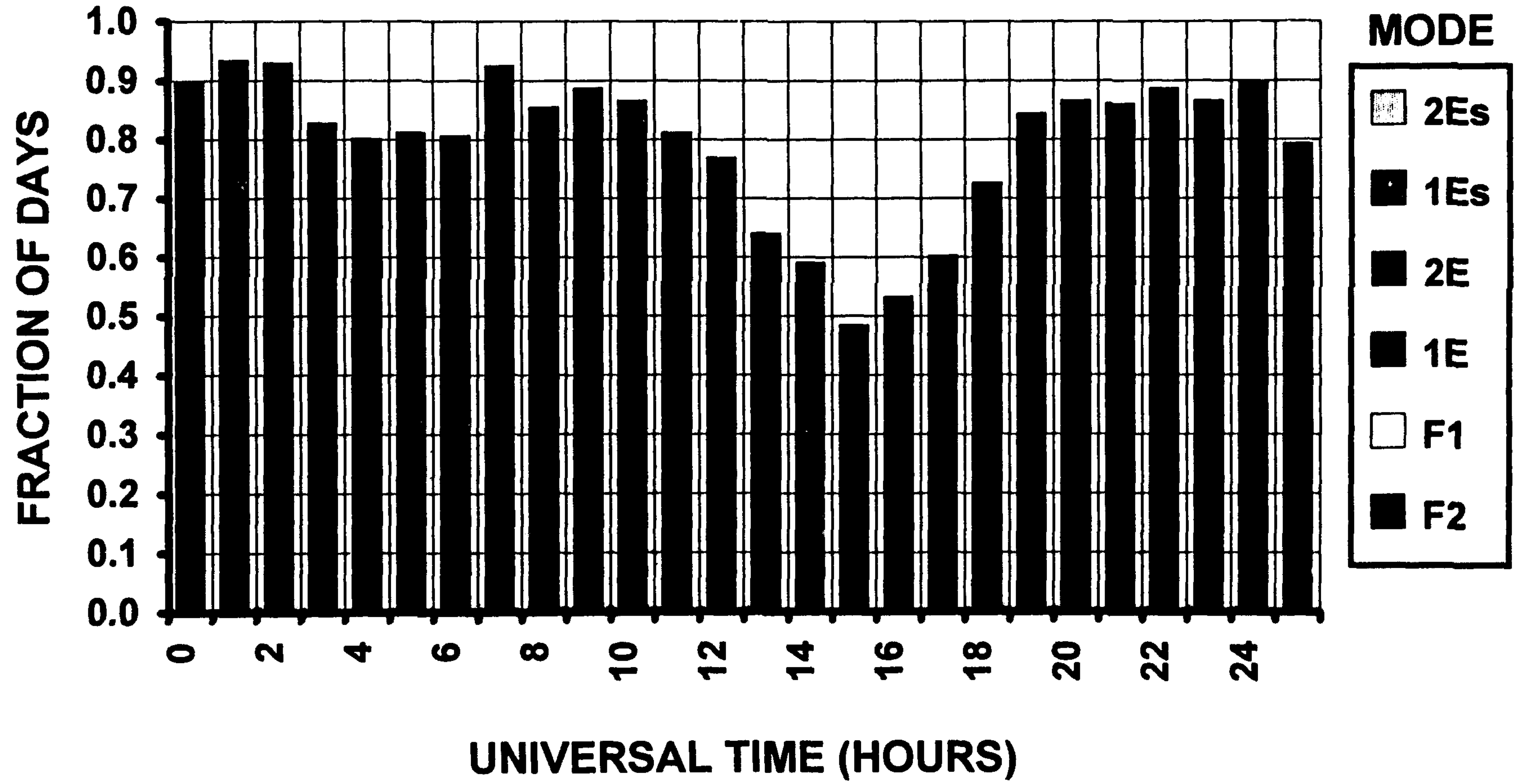
TABLE C.1 INDEX TO FREQUENCY DENSITY PLOTS

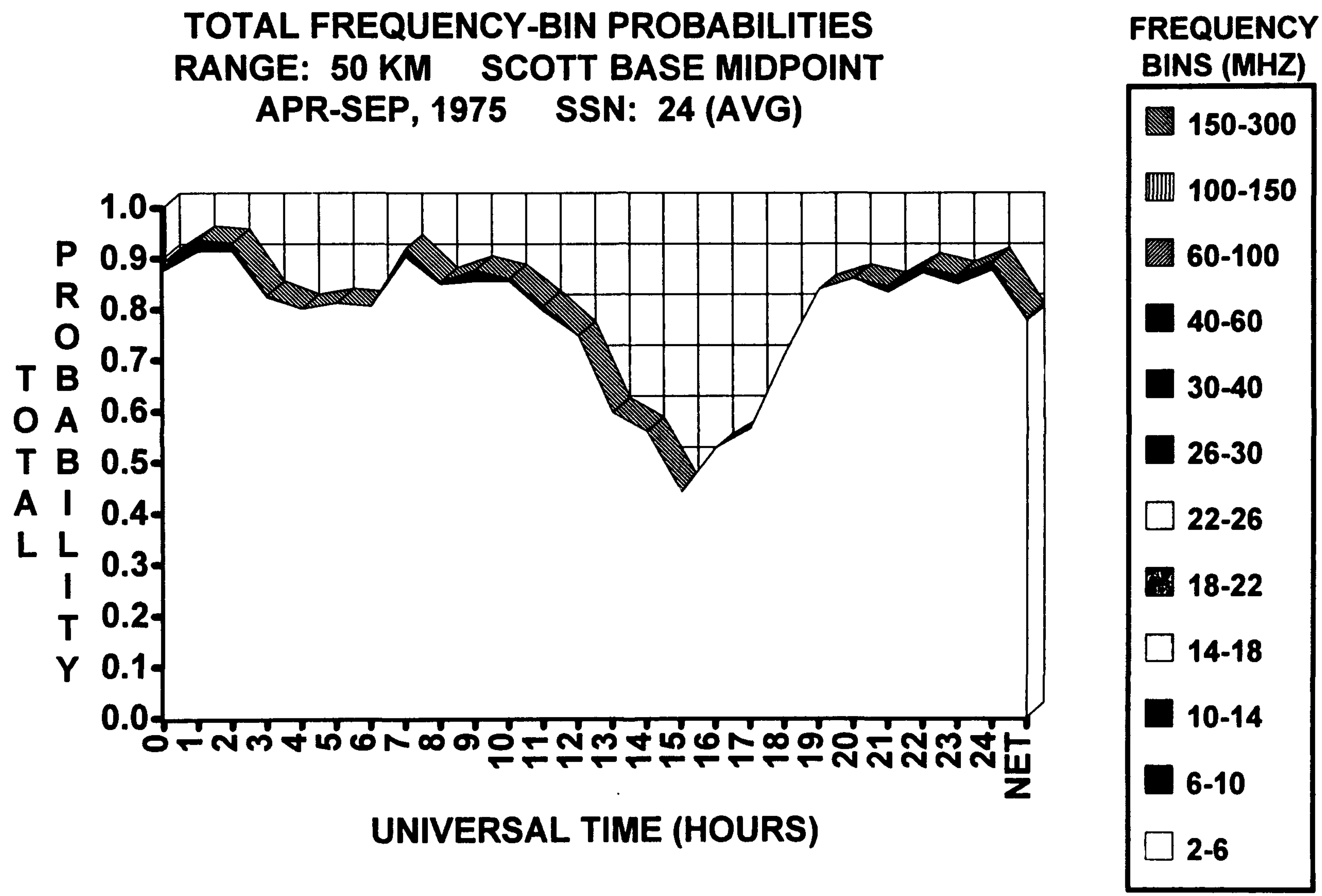
		JAN-MAR & OCT-DEC (MAXIMUM SUN)		APR-SEP (MINIMUM SUN)	
YEAR	PLOT	RANGE (KM)	PAGE NOS.	RANGE (KM)	PAGE NO.
1975	MODES	50	C-4	50	C-13
		200	C-6	200	C-15
		1000	C-8	1000	C-17
		2000	C-10	2000	C-19
	FREQ. DENSITY	50	C-5	50	C-14
		200	C-7	200	C-16
		1000	C-9	1000	C-18
		2000	C-11	2000	C-20
1979	MODES	50	C-22	50	C-31
		200	C-24	200	C-33
		1000	C-26	1000	C-35
		2000	C-28	2000	C-37
	FREQ. DENSITY	50	C-23	50	C-32
		200	C-25	200	C-34
		1000	C-27	1000	C-36
		2000	C-29	2000	C-38

TABLE C.2 INDEX TO FREQUENCY DENSITY PLOTS

		JAN-MAR & OCT-DEC (MAXIMUM SUN)		APR-SEP (MINIMUM SUN)	
YEAR	PLOT	RANGE (KM)	PAGE NOS.	RANGE (KM)	PAGE NO.
1975	MODES	50	C-4	50	C-13
		200	C-6	200	C-15
		1000	C-8	1000	C-17
		2000	C-10	2000	C-19
	FREQ. DENSITY	50	C-5	50	C-14
		200	C-7	200	C-16
		1000	C-9	1000	C-18
		2000	C-11	2000	C-20
1979	MODES	50	C-22	50	C-31
		200	C-24	200	C-33
		1000	C-26	1000	C-35
		2000	C-28	2000	C-37
	FREQ. DENSITY	50	C-23	50	C-32
		200	C-25	200	C-34
		1000	C-27	1000	C-36
		2000	C-29	2000	C-38

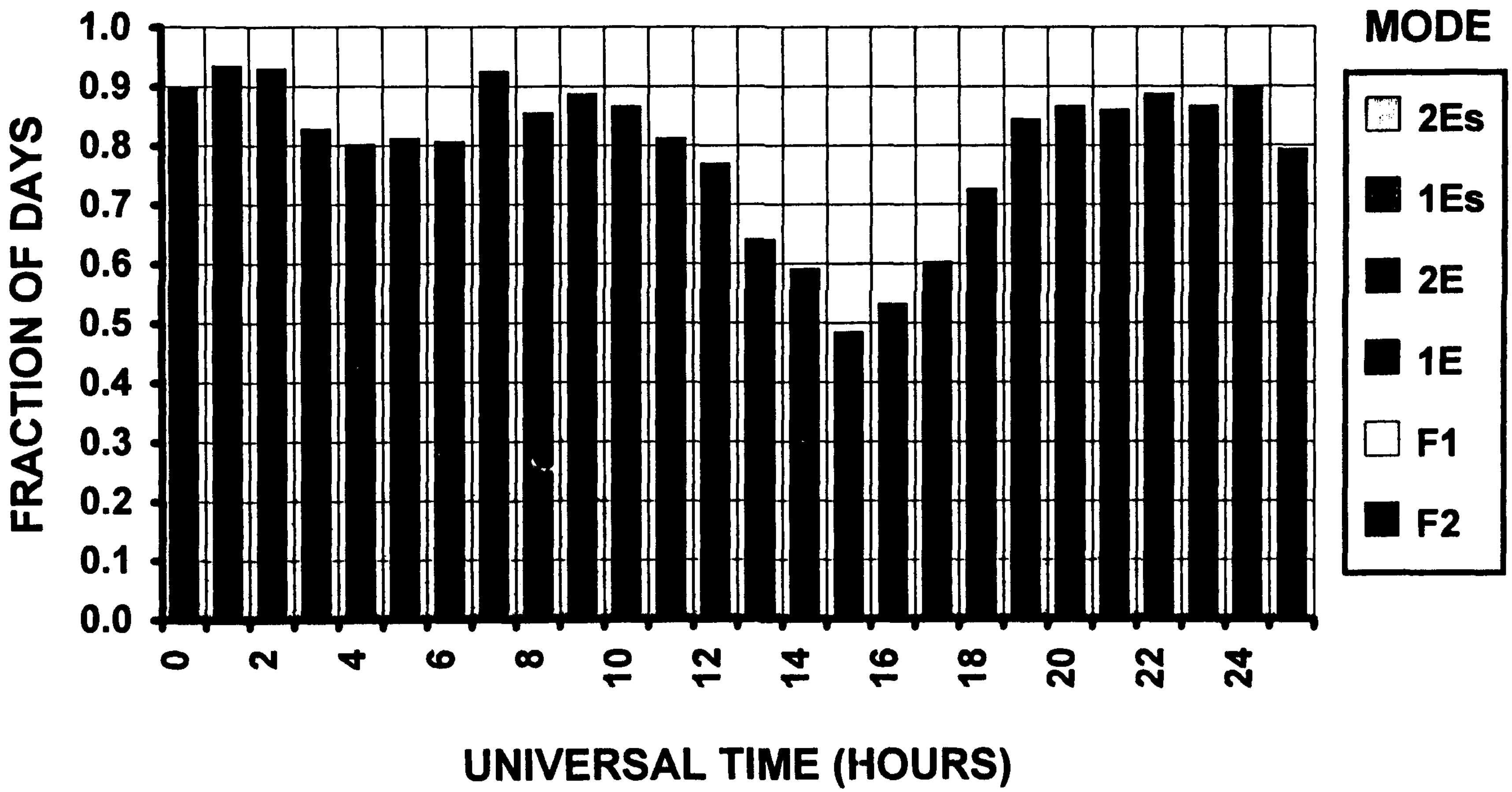
PROPAGATION MODE AVAILABILITY: 50-KM LINK
APRIL-SEPTEMBER, 1975

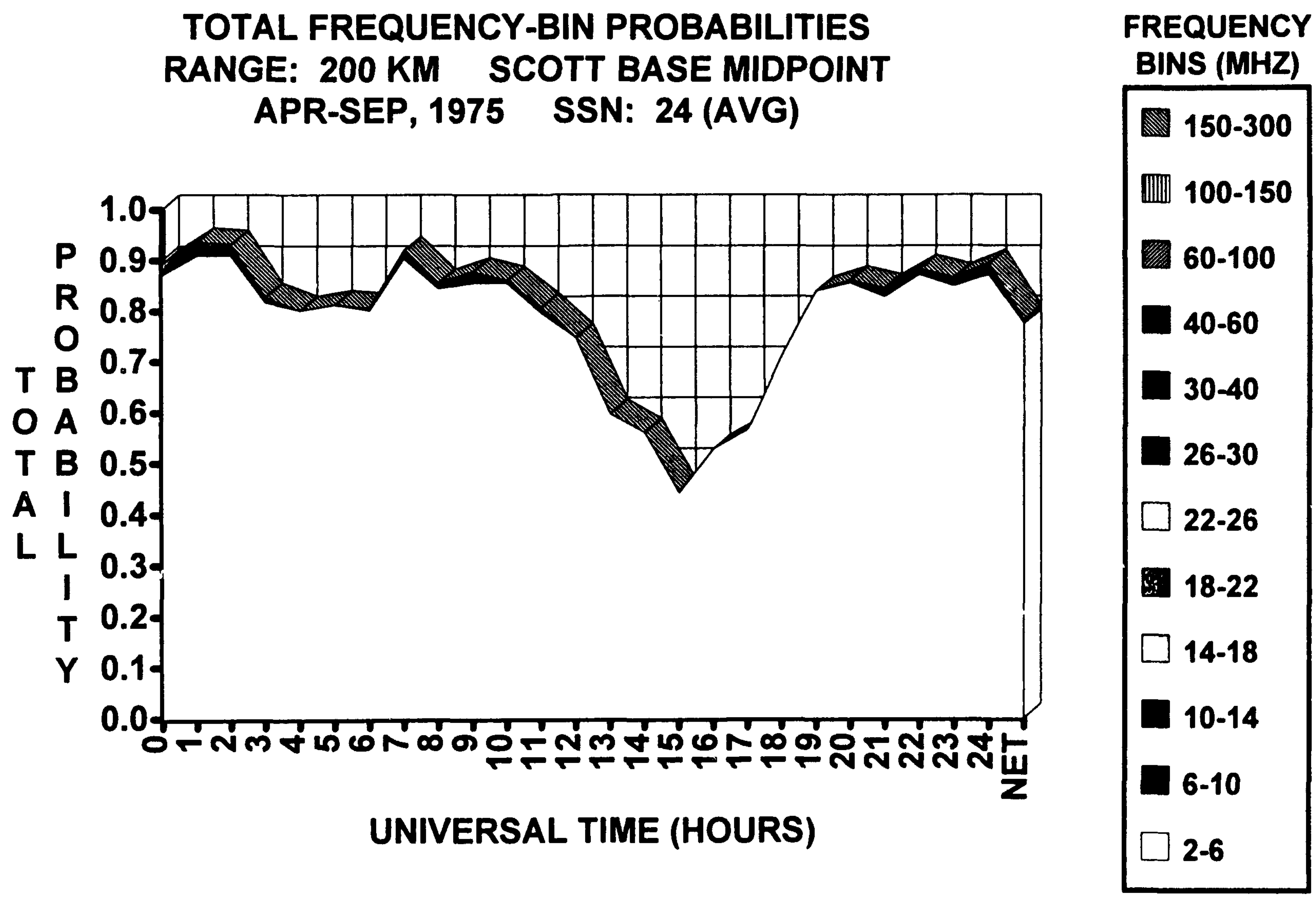


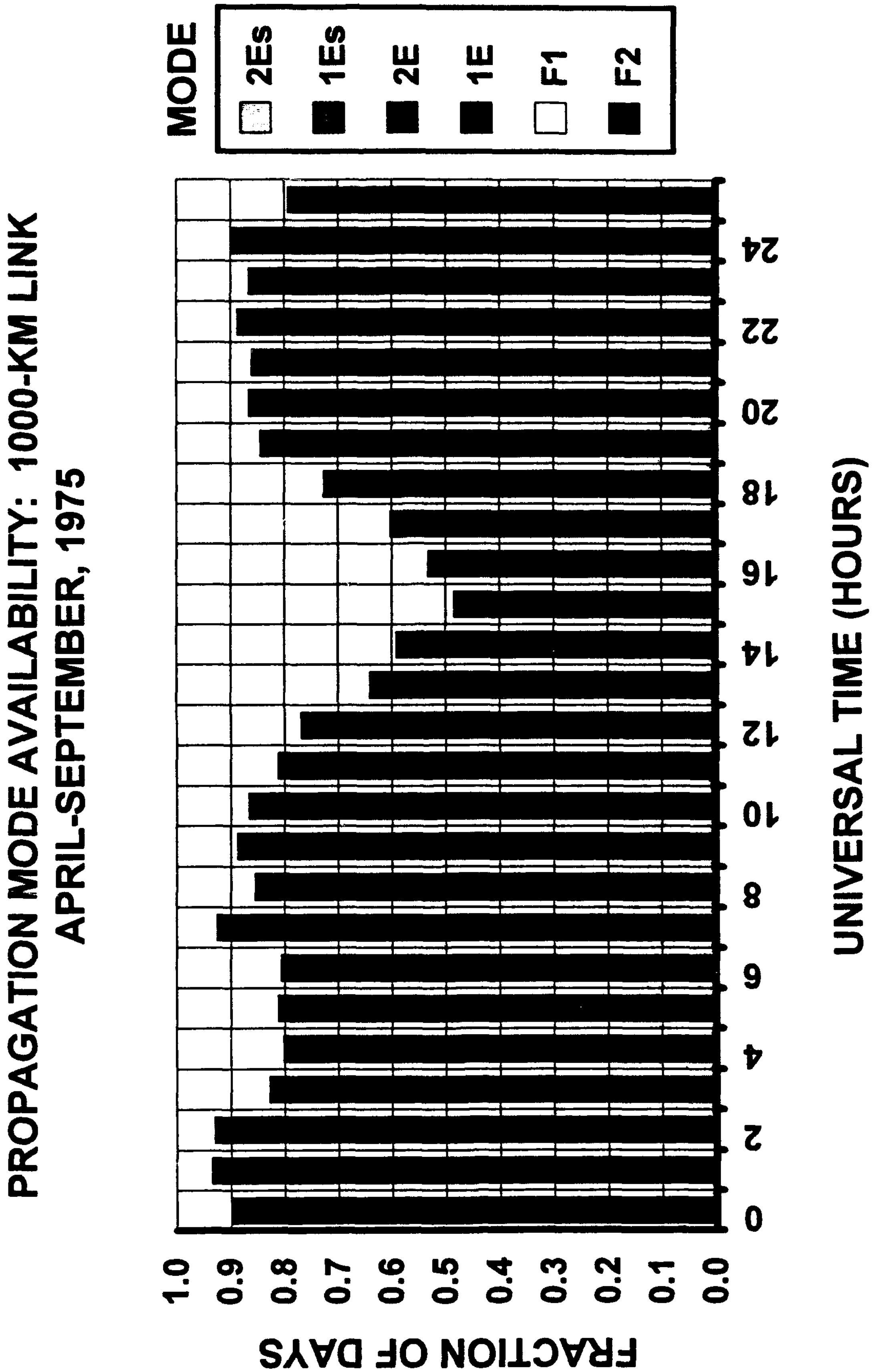


TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 50 KM SCOTT BASE MIDPOINT
APR-SEP, 1975 SSN: 24 (AVG)
TOTAL PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 NET
UNIVERSAL TIME (HOURS)
FREQUENCY BINS (MHZ)
150-300
100-150
60-100
40-60
30-40
26-30
22-26
18-22
14-18
10-14
6-10
2-6

PROPAGATION MODE AVAILABILITY: 200-KM LINK
APRIL-SEPTEMBER, 1975

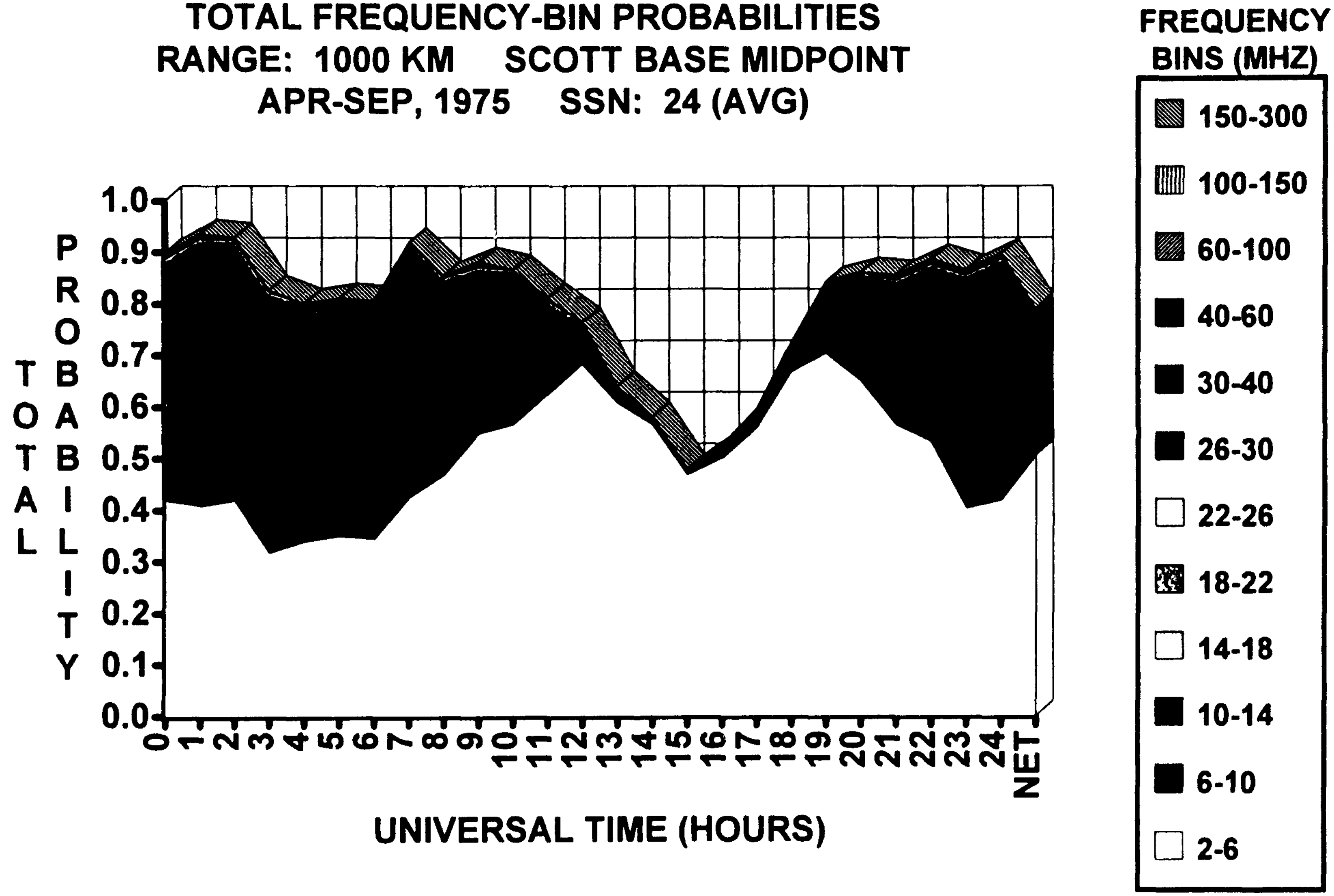



TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 200 KM SCOTT BASE MIDPOINT
APR-SEP, 1975 SSN: 24 (AVG)
TOTAL PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
NET
UNIVERSAL TIME (HOURS)
FREQUENCY BINS (MHZ)
150-300
100-150
60-100
40-60
30-40
26-30
22-26
18-22
14-18
10-14
6-10
2-6

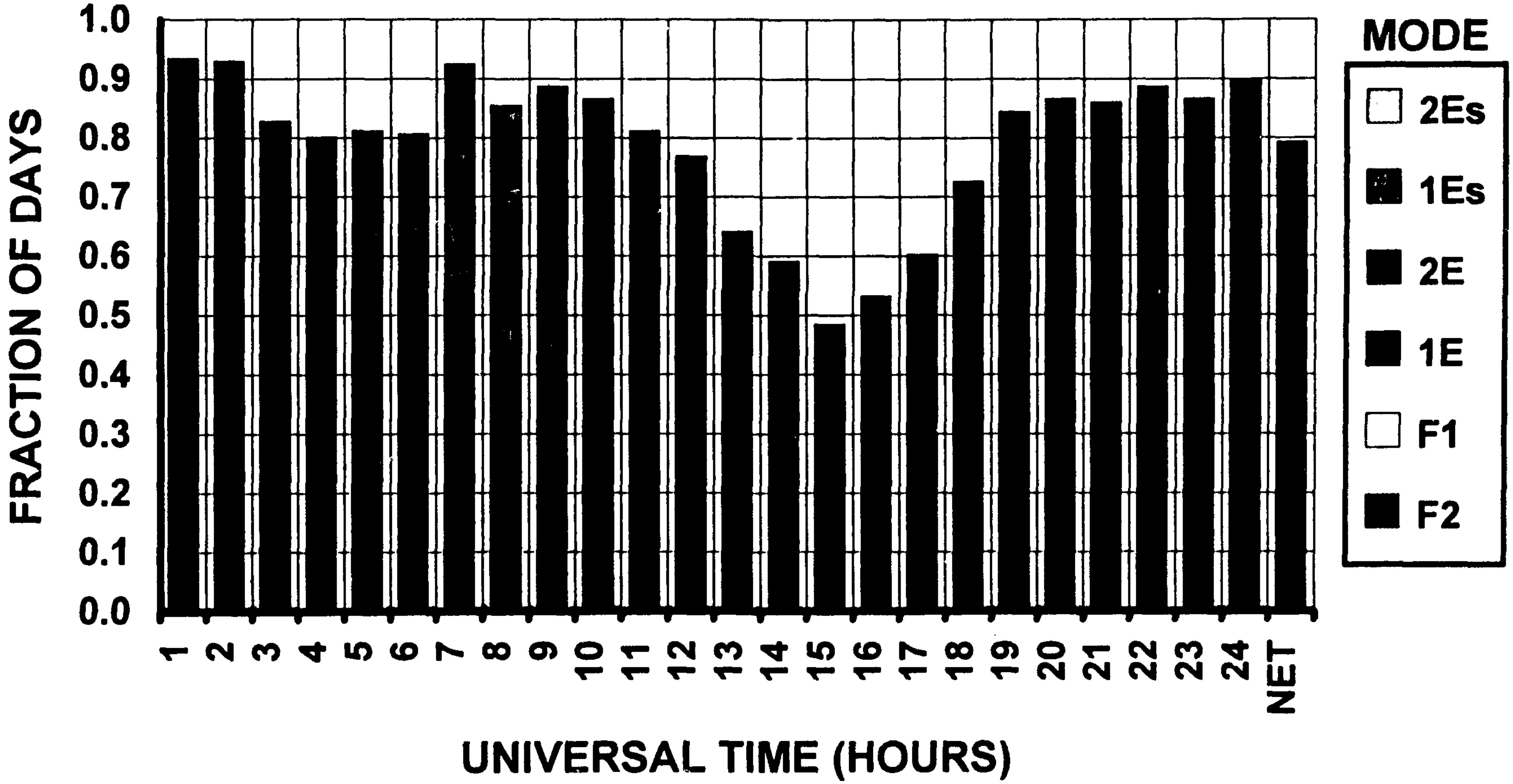


PROPAGATION MODE AVAILABILITY: 1000-KM LINK
APRIL-SEPTEMBER, 1975
MODE
2Es
1Es
2E
1E
F1
F2
FRACTION OF DAYS
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
UNIVERSAL TIME (HOURS)
0
2
4
6
8
10
12
14
16
18
20
22
24

TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 1000 KM SCOTT BASE MIDPOINT
APR-SEP, 1975 SSN: 24 (AVG)



PROPAGATION MODE AVAILABILITY: 2000-KM LINK
APRIL-SEPTEMBER, 1975



TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 2000 KM SCOTT BASE MIDPOINT
APR-SEP, 1975 SSN: 24 (AVG)

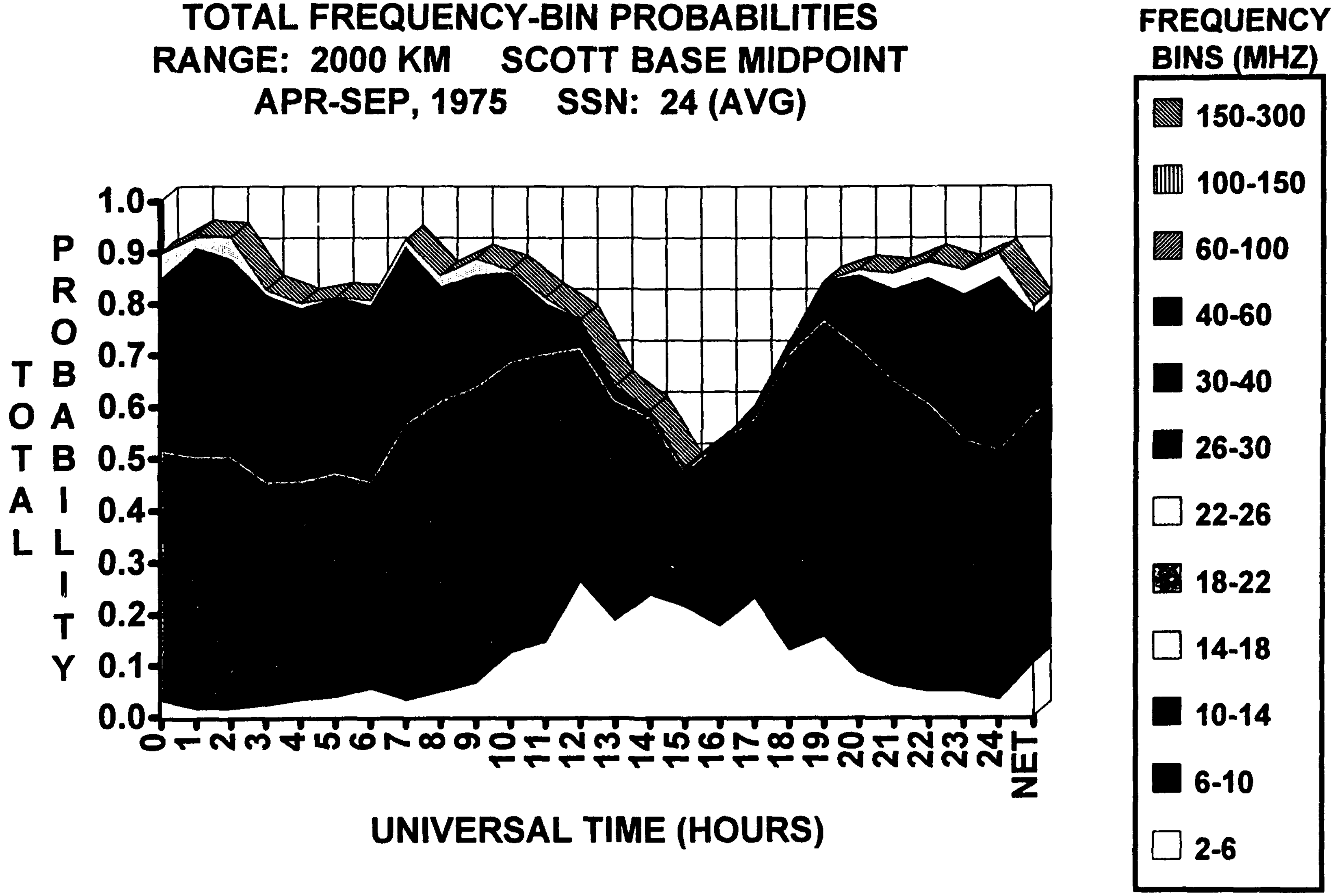
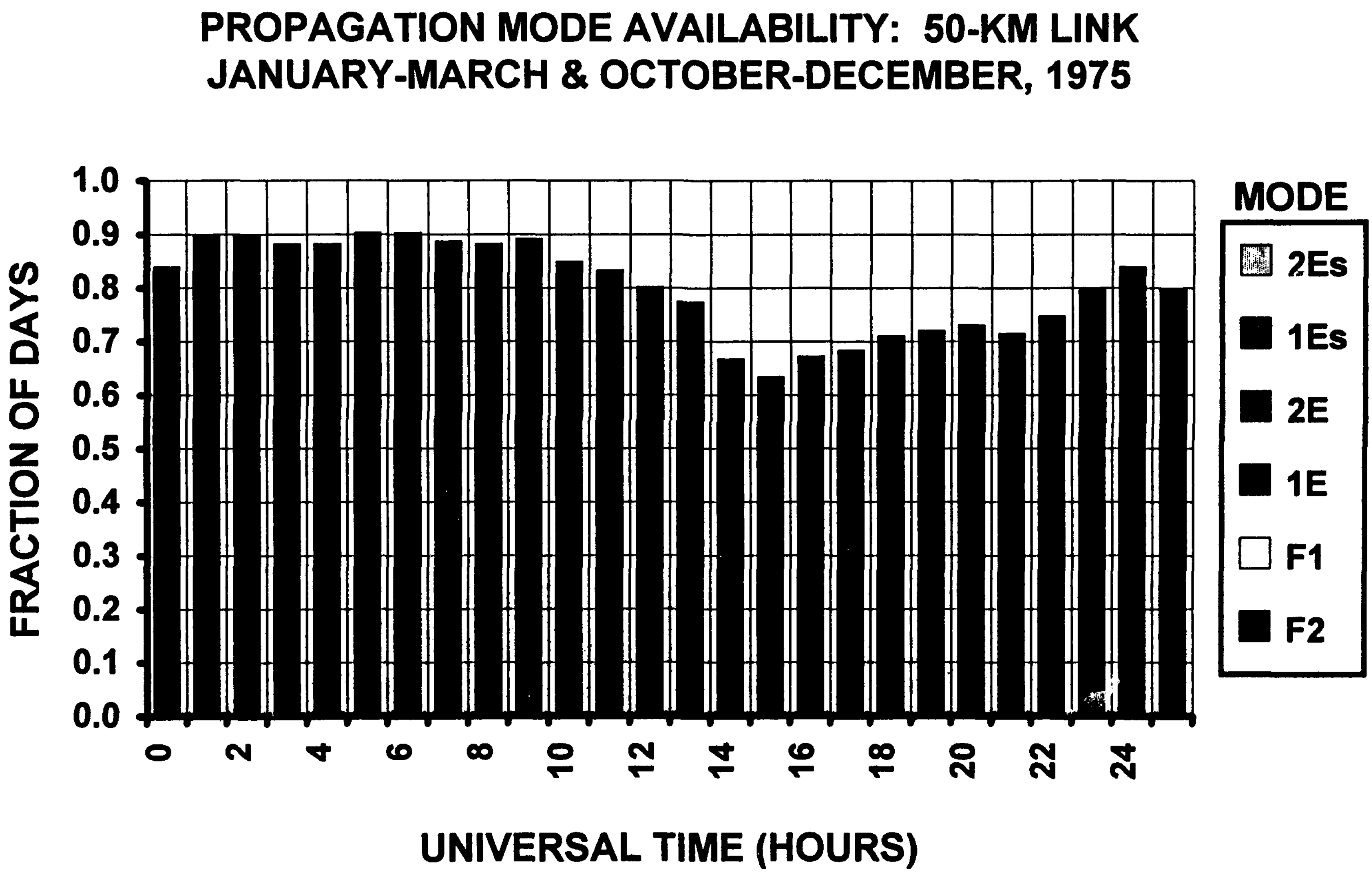


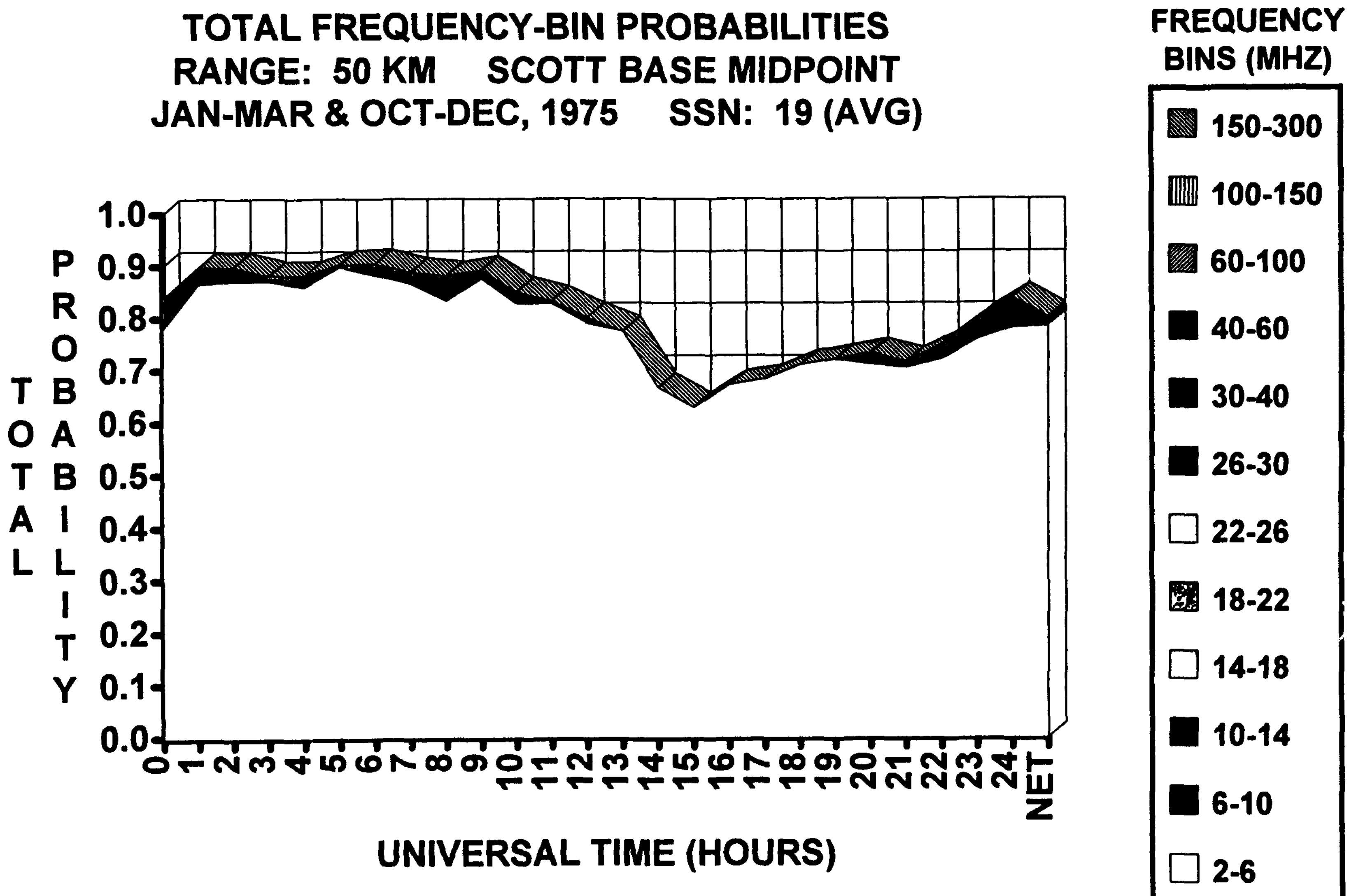
TABLE C.3 INDEX TO FREQUENCY DENSITY PLOTS

		JAN-MAR & OCT-DEC (MAXIMUM SUN)		APR-SEP (MINIMUM SUN)	
YEAR	PLOT	RANGE (KM)	PAGE NOS.	RANGE (KM)	PAGE NO.
1975	MODES	50	C-4	50	C-13
		200	C-6	200	C-15
		1000	C-8	1000	C-17
		2000	C-10	2000	C-19
	FREQ. DENSITY	50	C-5	50	C-14
		200	C-7	200	C-16
		1000	C-9	1000	C-18
		2000	C-11	2000	C-20
1979	MODES	50	C-22	50	C-31
		200	C-24	200	C-33
		1000	C-26	1000	C-35
		2000	C-28	2000	C-37
	FREQ. DENSITY	50	C-23	50	C-32
		200	C-25	200	C-34
		1000	C-27	1000	C-36
		2000	C-29	2000	C-38

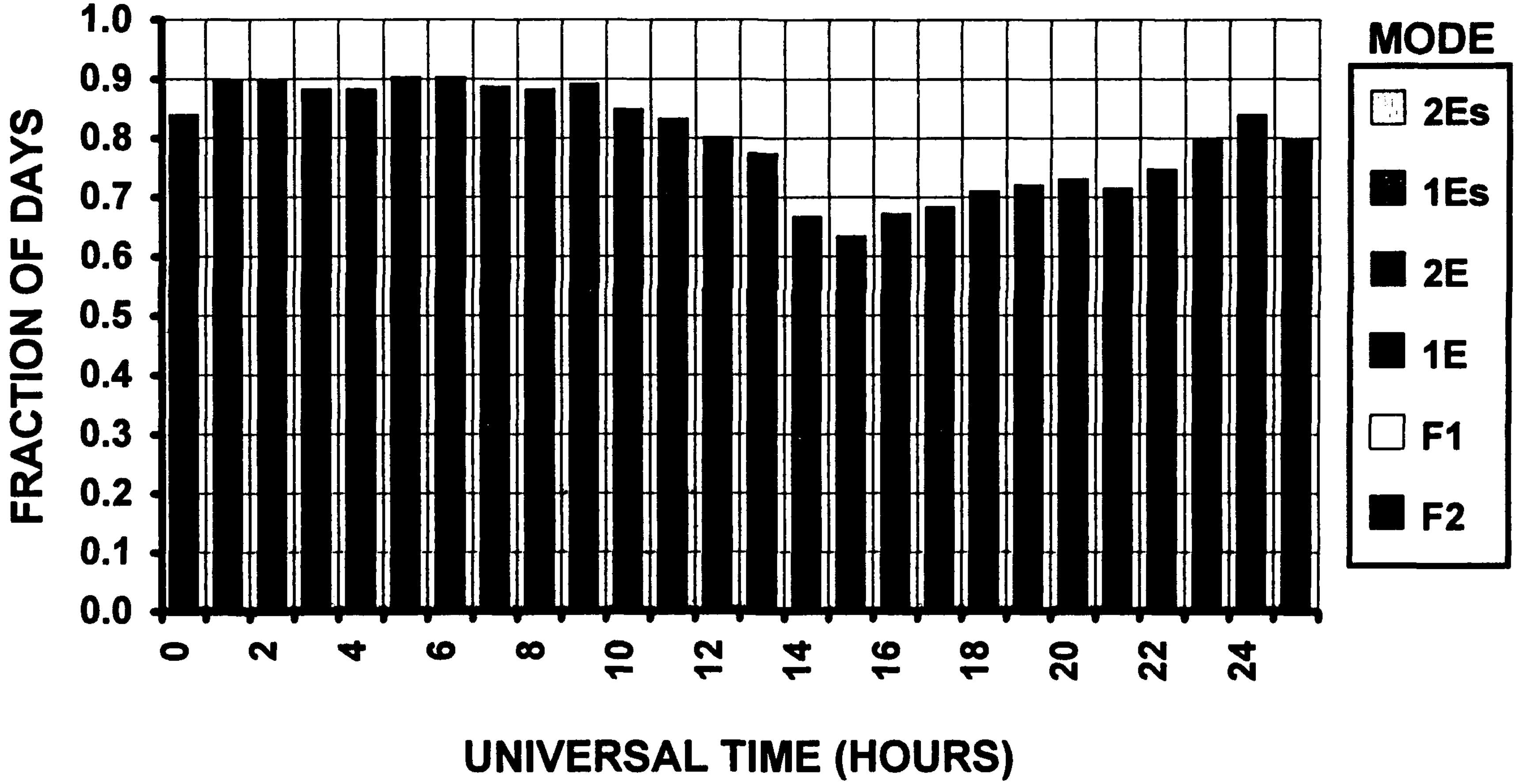


PROPAGATION MODE AVAILABILITY: 50-KM LINK
JANUARY-MARCH & OCTOBER-DECEMBER, 1975
FRACTION OF DAYS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
20
22
24
UNIVERSAL TIME (HOURS)
MODE
2Es
1Es
2E
1E
F1
F2

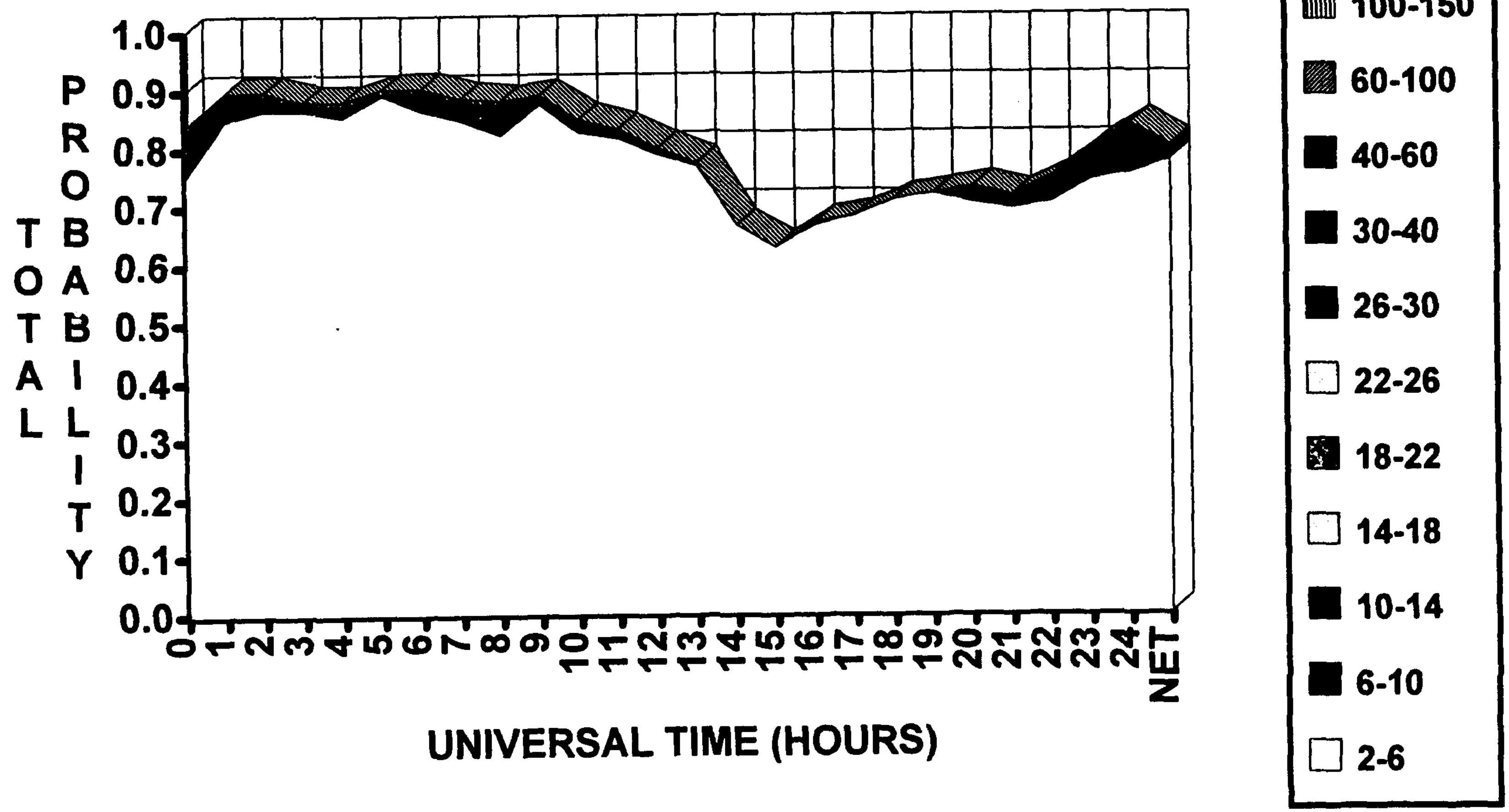
TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 50 KM SCOTT BASE MIDPOINT
JAN-MAR & OCT-DEC, 1975 SSN: 19 (AVG)



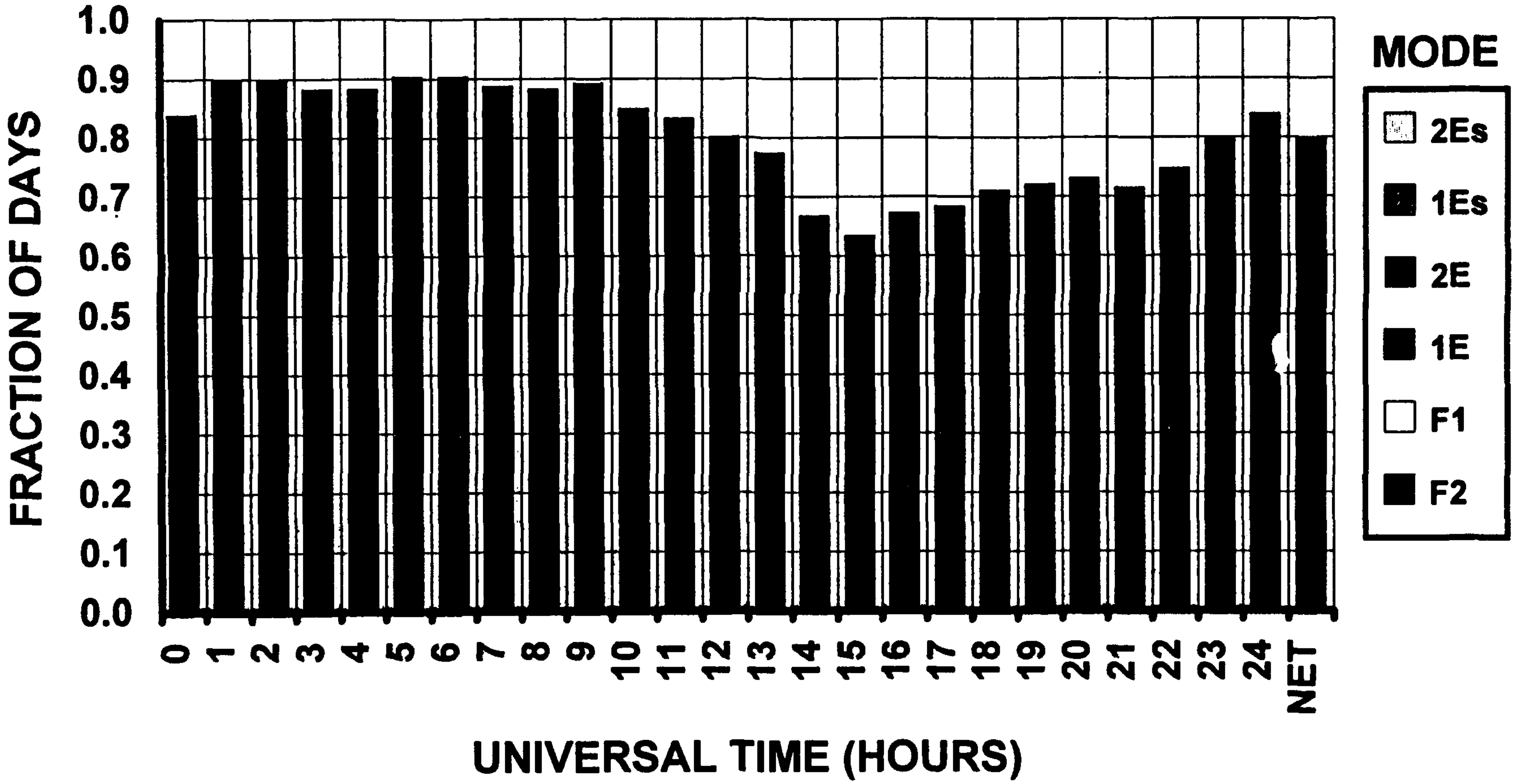
PROPAGATION MODE AVAILABILITY: 200-KM LINK
JANUARY-MARCH & OCTOBER-DECEMBER, 1975



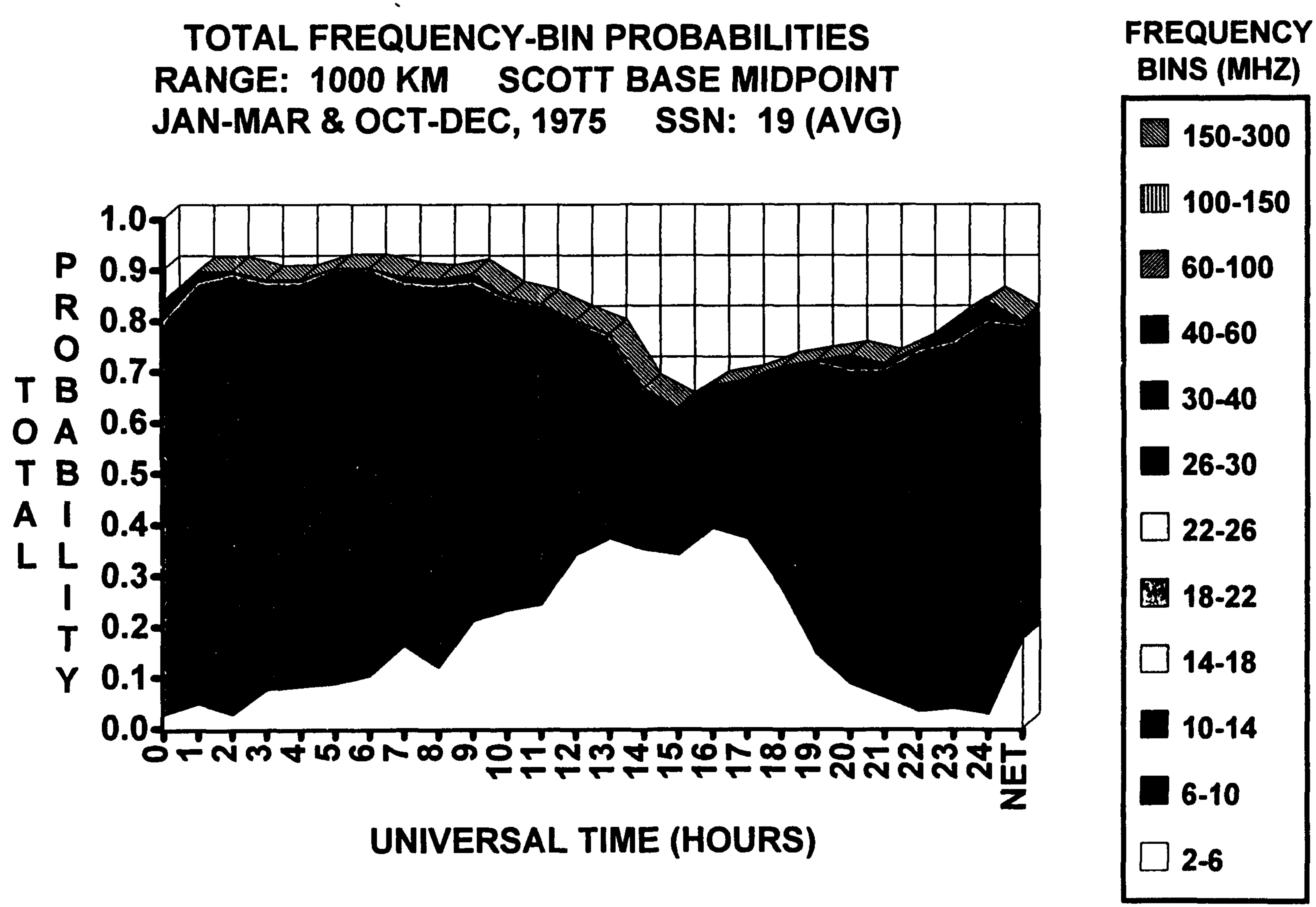
TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 200 KM SCOTT BASE MIDPOINT
JAN-MAR & OCT-DEC, 1975 SSN: 19 (AVG)



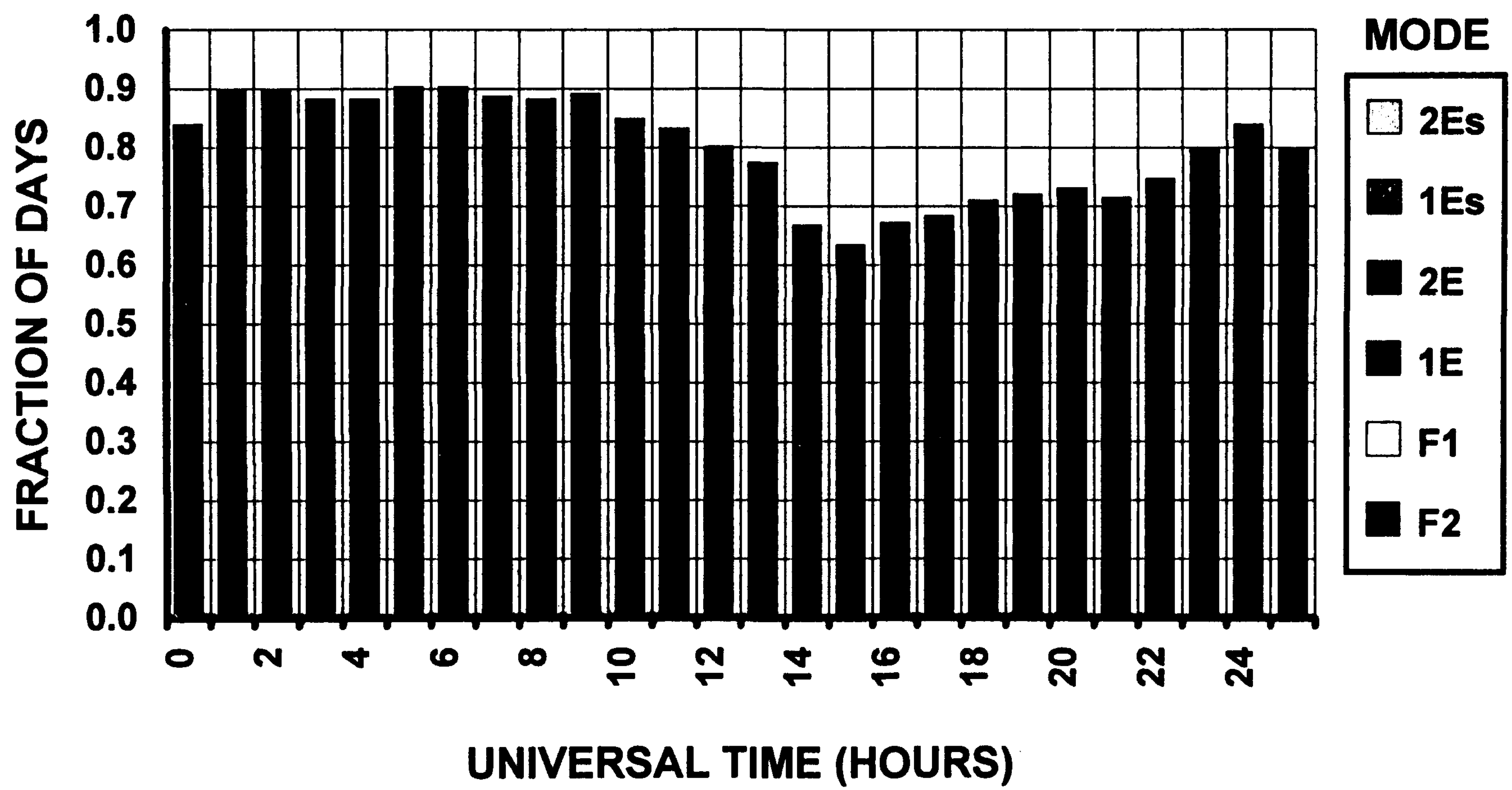
PROPAGATION MODE AVAILABILITY: 1000-KM LINK
JANUARY-MARCH & OCTOBER-DECEMBER, 1975



TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 1000 KM SCOTT BASE MIDPOINT
JAN-MAR & OCT-DEC, 1975 SSN: 19 (AVG)



PROPAGATION MODE AVAILABILITY: 2000-KM LINK
JANUARY-MARCH & OCTOBER-DECEMBER, 1975



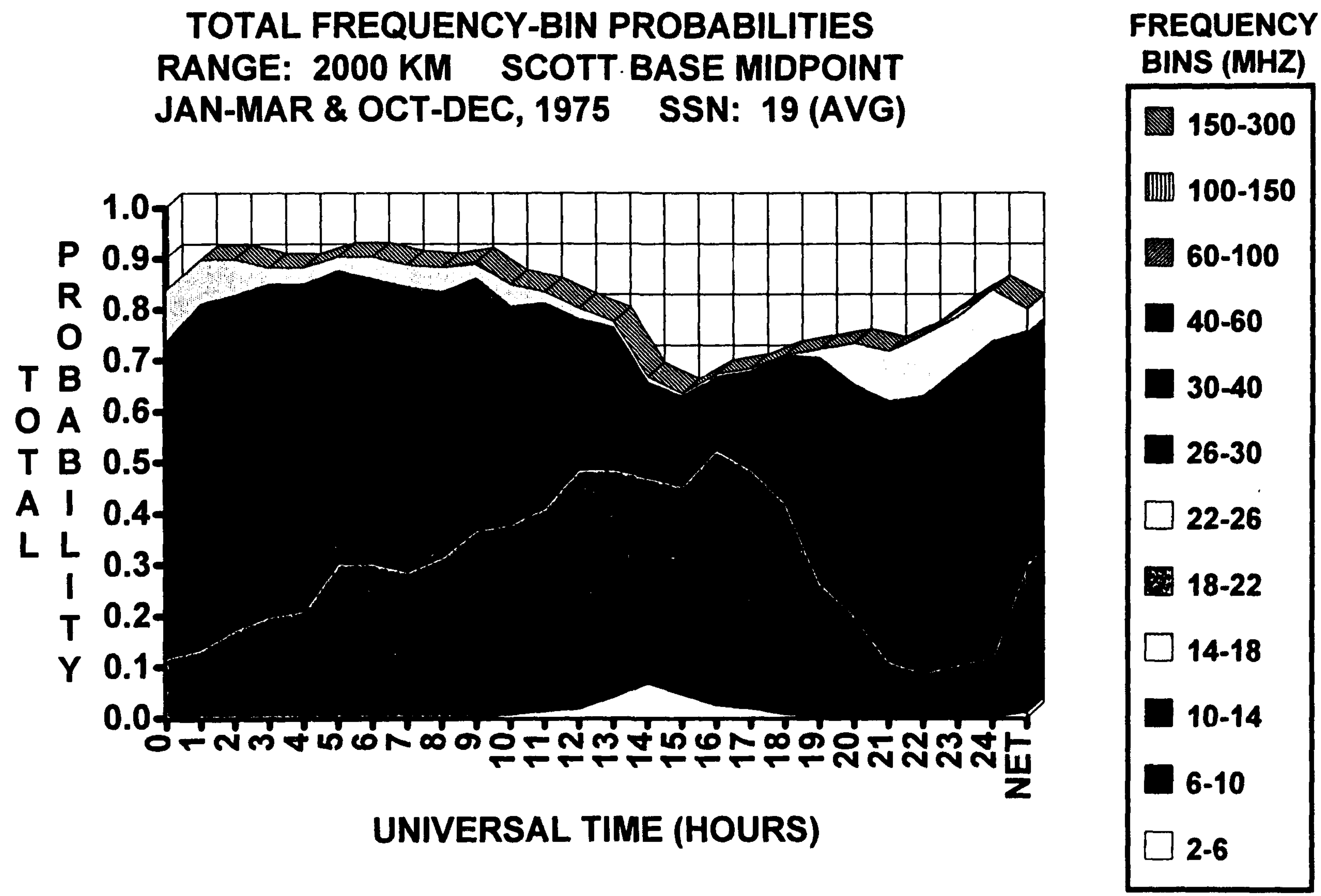
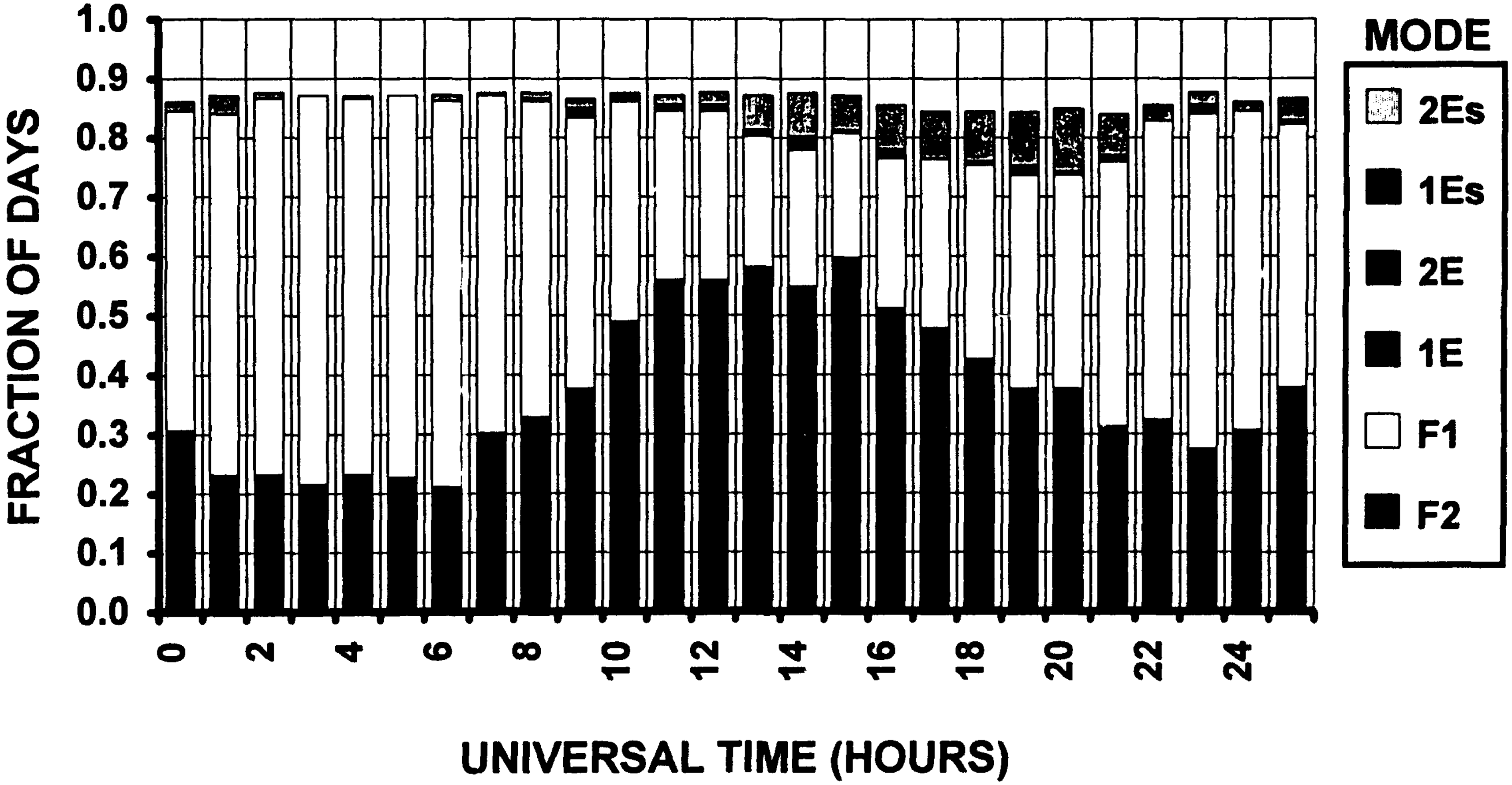
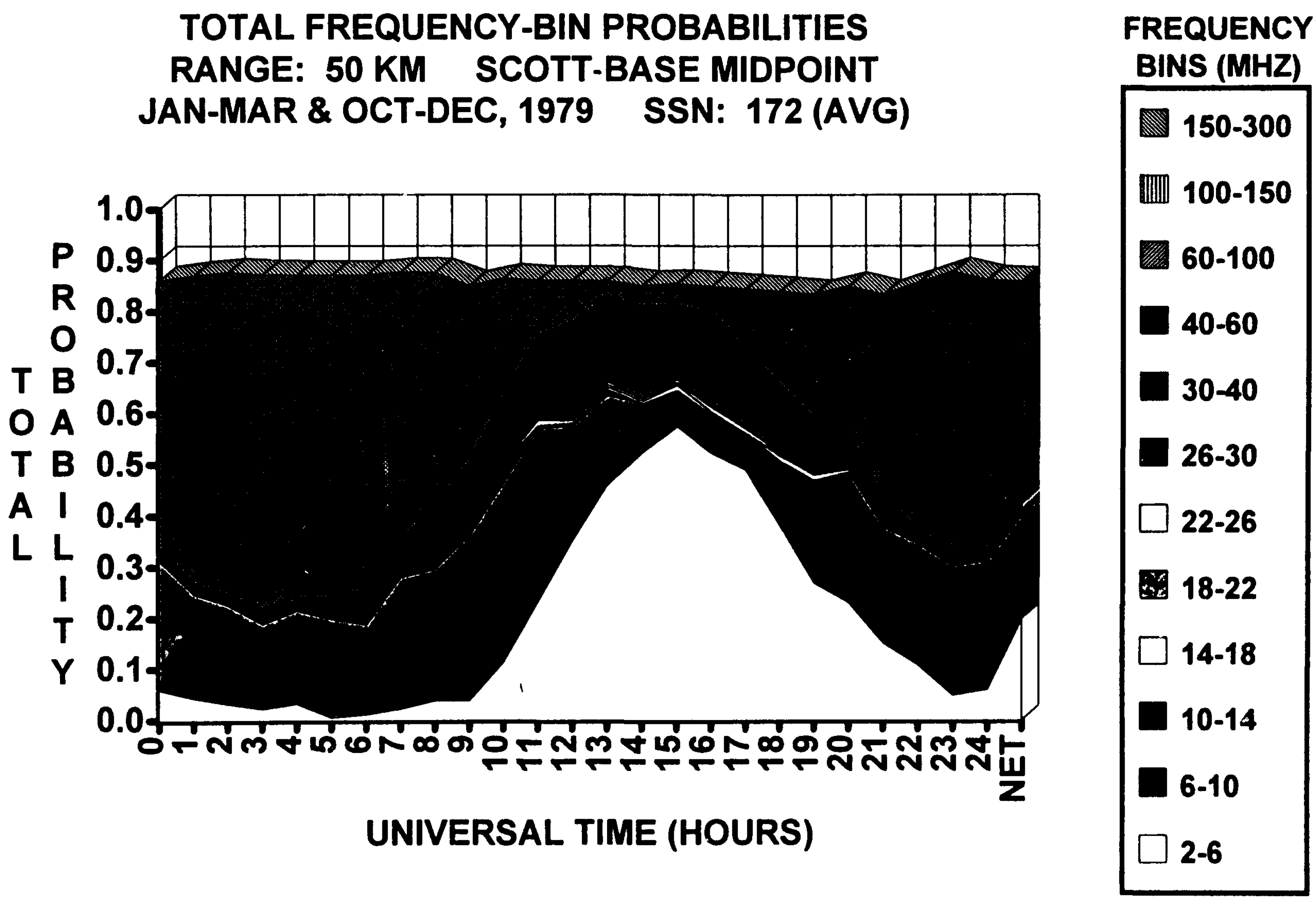

TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 2000 KM SCOTT BASE MIDPOINT
JAN-MAR & OCT-DEC, 1975 SSN: 19 (AVG)
TOTAL PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 NET
UNIVERSAL TIME (HOURS)
FREQUENCY BINS (MHZ)
150-300
100-150
60-100
40-60
30-40
26-30
22-26
18-22
14-18
10-14
6-10
2-6

TABLE C.4 INDEX TO FREQUENCY DENSITY PLOTS

YEAR	PLOT	JAN-MAR & OCT-DEC (MAXIMUM SUN)		APR-SEP (MINIMUM SUN)	
		RANGE (KM)	PAGE NOS.	RANGE (KM)	PAGE NO.
1975	MODES	50	C-4	50	C-13
		200	C-6	200	C-15
		1000	C-8	1000	C-17
		2000	C-10	2000	C-19
	FREQ. DENSITY	50	C-5	50	C-14
		200	C-7	200	C-16
		1000	C-9	1000	C-18
		2000	C-11	2000	C-20
1979	MODES	50	C-22	50	C-31
		200	C-24	200	C-33
		1000	C-26	1000	C-35
		2000	C-28	2000	C-37
	FREQ. DENSITY	50	C-23	50	C-32
		200	C-25	200	C-34
		1000	C-27	1000	C-36
		2000	C-29	2000	C-38

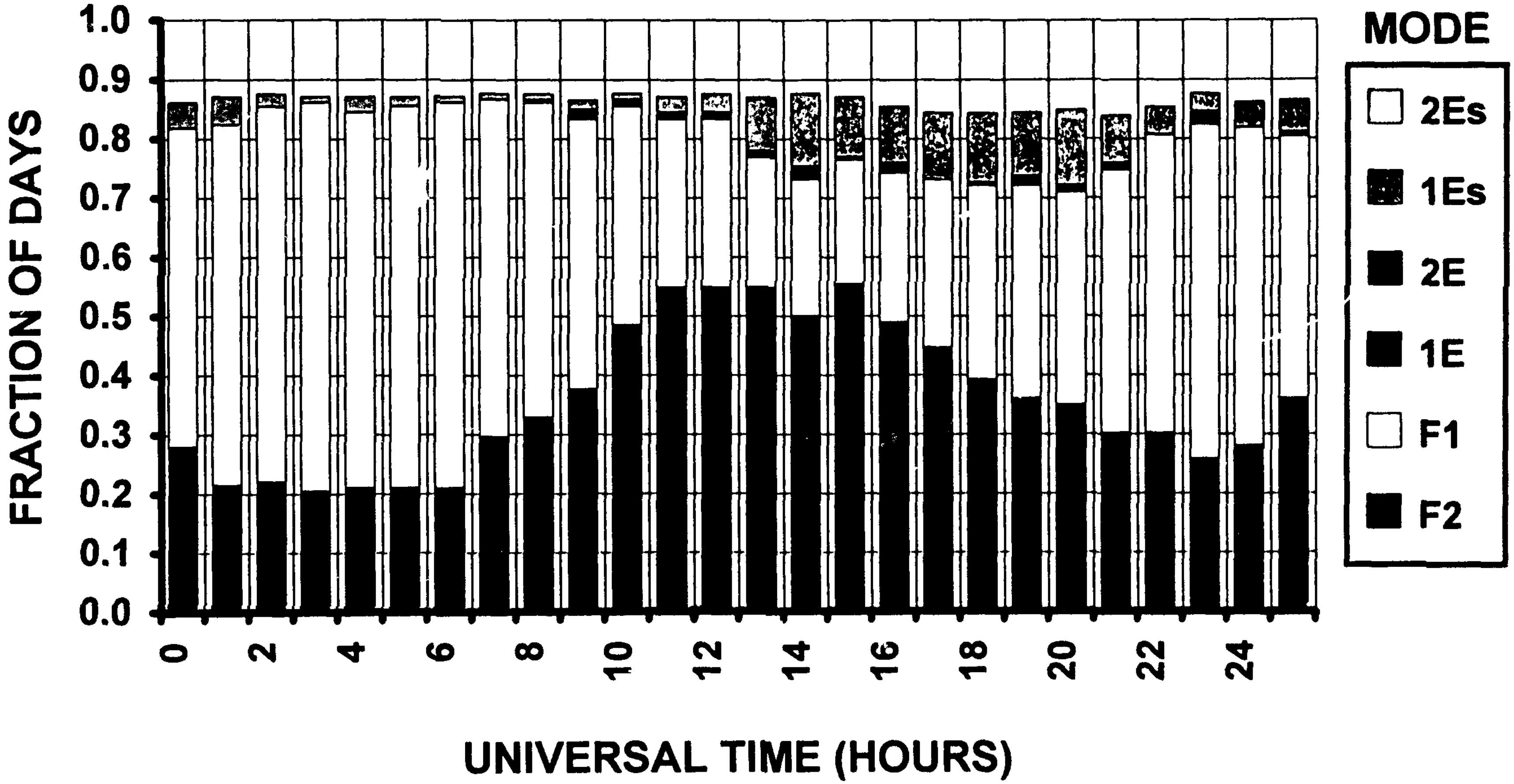
PROPAGATION MODE AVAILABILITY: 50-KM LINK
JANUARY-MARCH & OCTOBER-DECEMBER, 1979

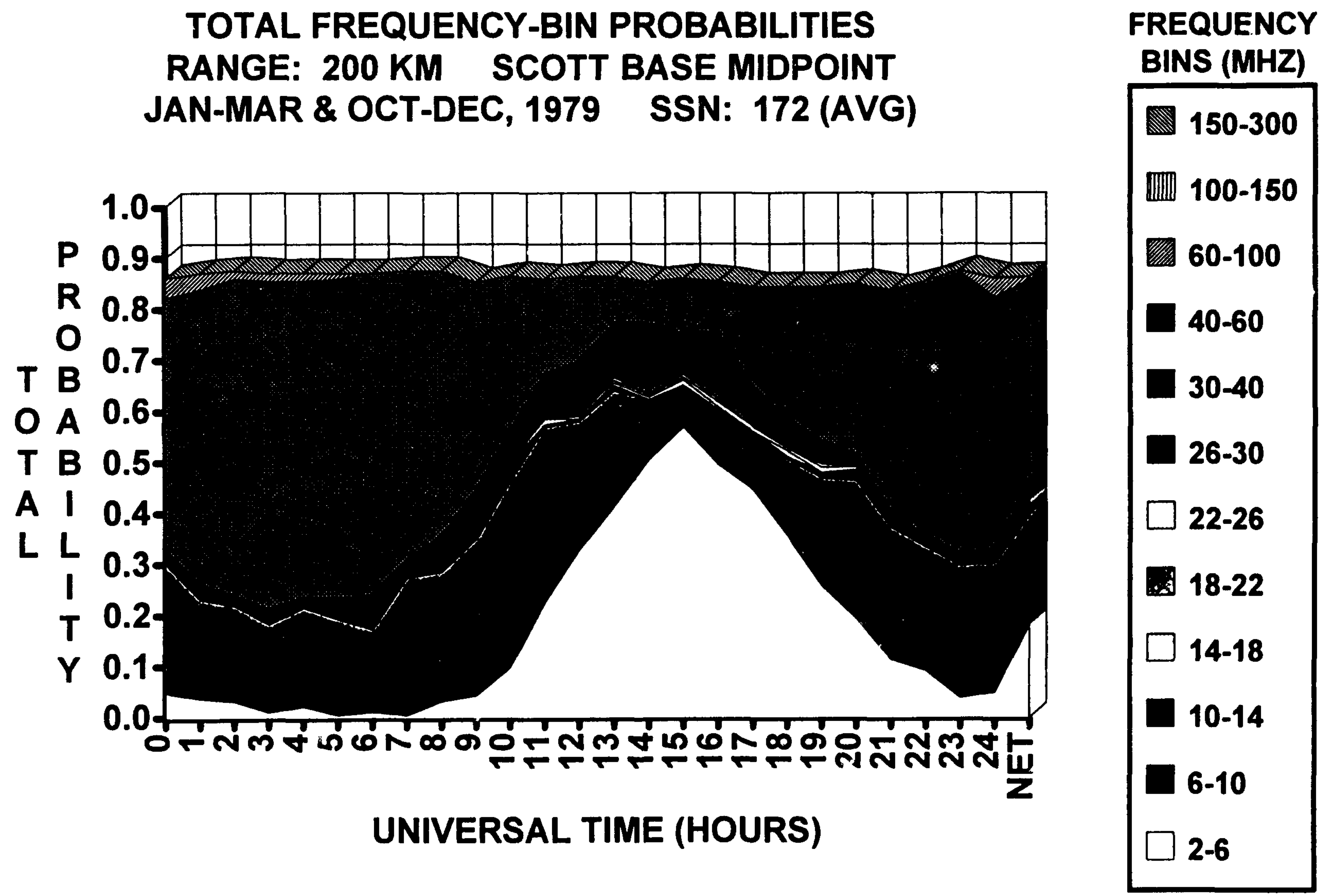




TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 50 KM SCOTT-BASE MIDPOINT
JAN-MAR & OCT-DEC, 1979 SSN: 172 (AVG)
TOTAL PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 NET
UNIVERSAL TIME (HOURS)
FREQUENCY BINS (MHZ)
150-300
100-150
60-100
40-60
30-40
26-30
22-26
18-22
14-18
10-14
6-10
2-6

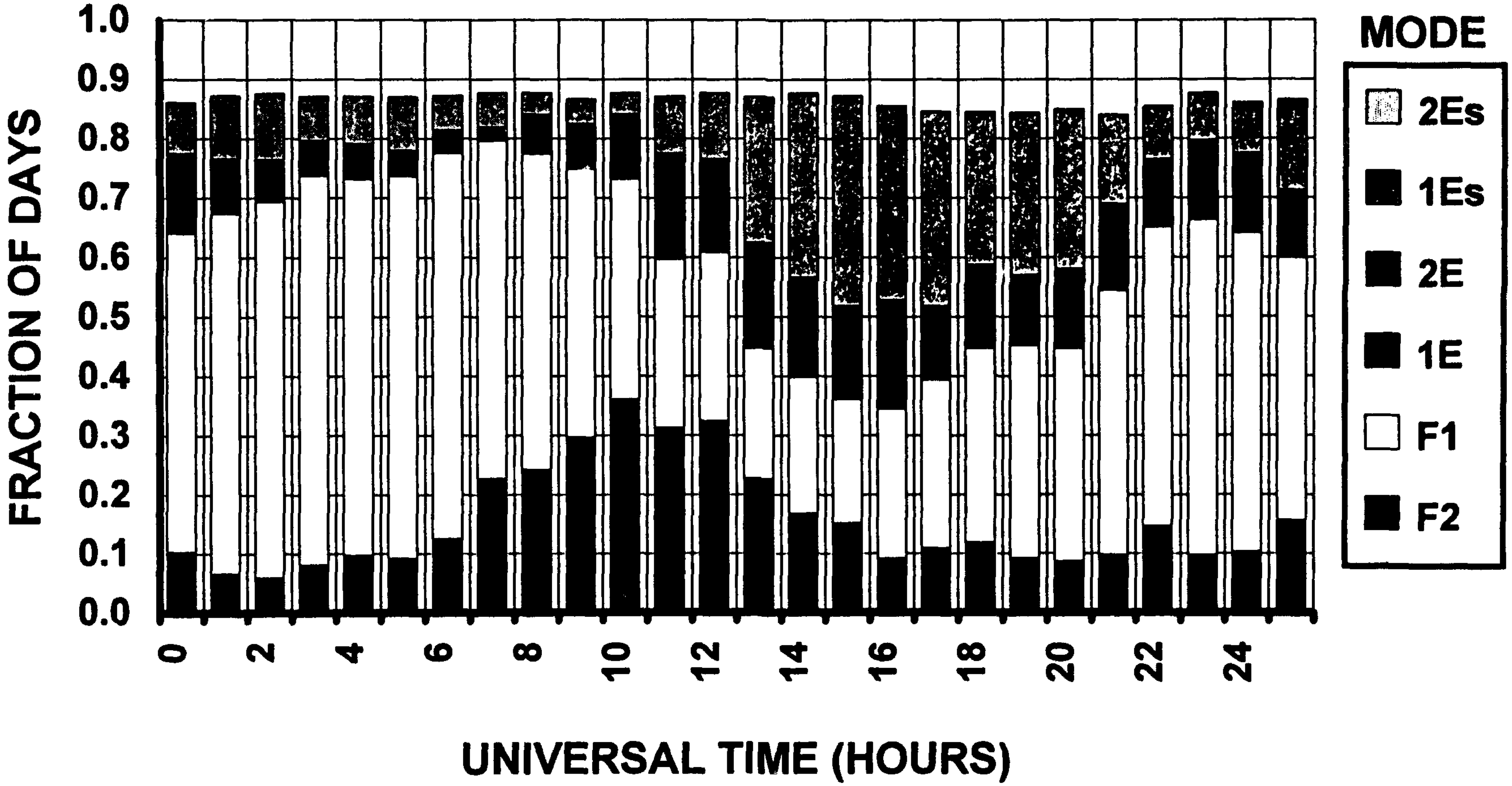
PROPAGATION MODE AVAILABILITY: 200-KM LINK
JANUARY-MARCH & OCTOBER-DECEMBER, 1979



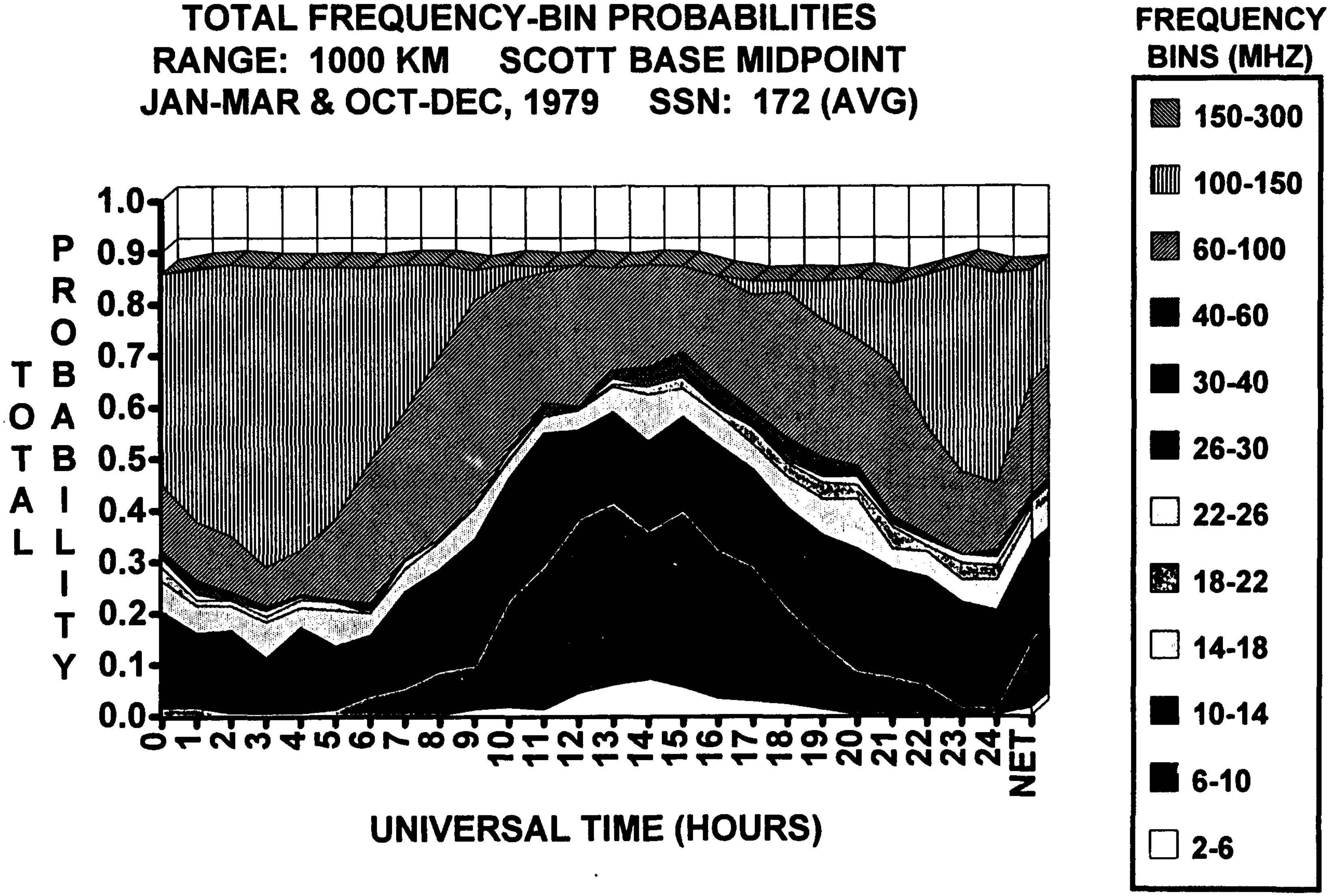


TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 200 KM SCOTT BASE MIDPOINT
JAN-MAR & OCT-DEC, 1979 SSN: 172 (AVG)
TOTAL PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 NET
UNIVERSAL TIME (HOURS)
FREQUENCY BINS (MHZ)
150-300
100-150
60-100
40-60
30-40
26-30
22-26
18-22
14-18
10-14
6-10
2-6

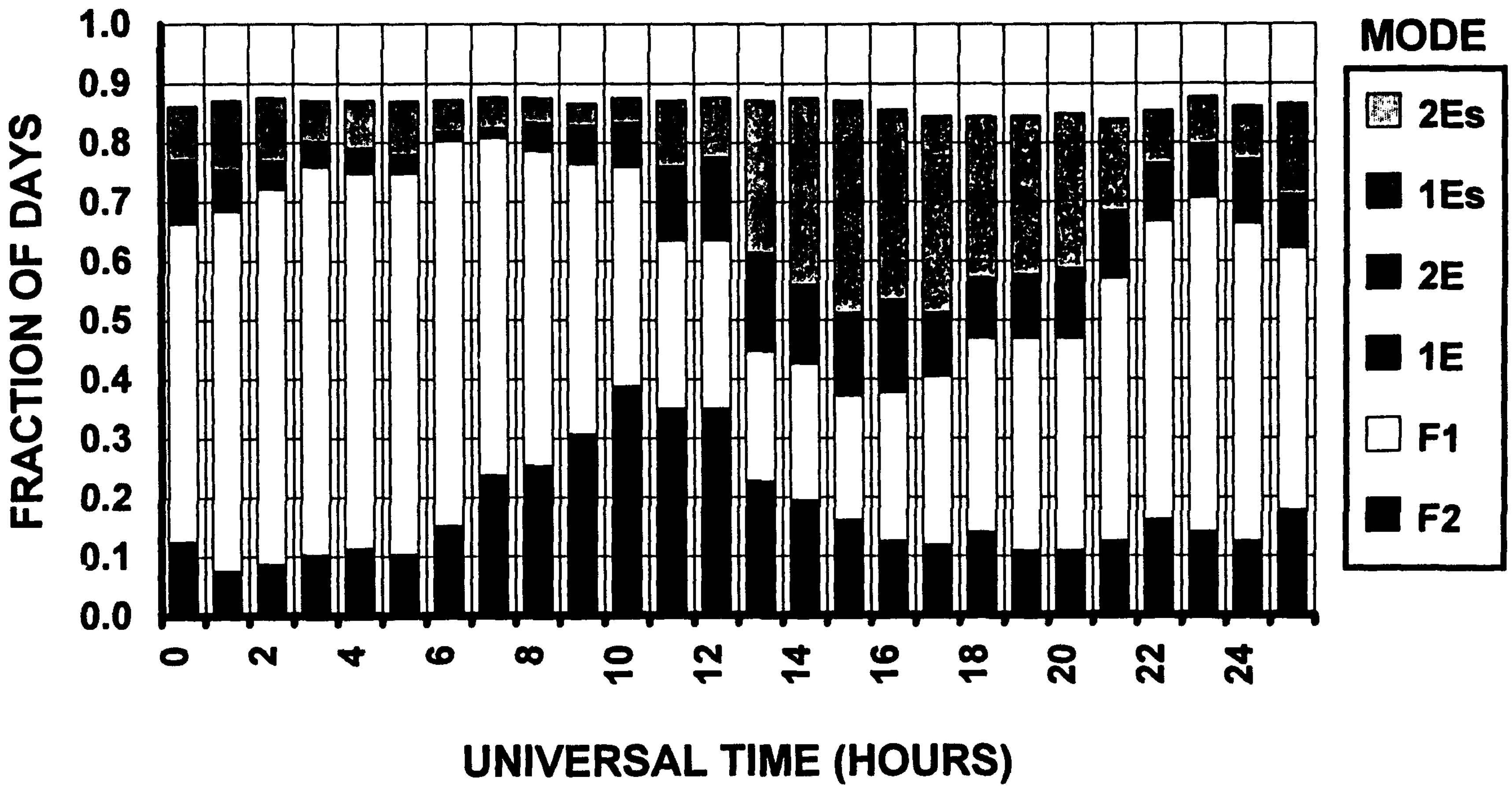
PROPAGATION MODE AVAILABILITY: 1000-KM LINK
JANUARY-MARCH & OCTOBER-DECEMBER, 1979



TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 1000 KM SCOTT BASE MIDPOINT
JAN-MAR & OCT-DEC, 1979 SSN: 172 (AVG)



PROPAGATION MODE AVAILABILITY: 2000-KM LINK
JANUARY-MARCH & OCTOBER-DECEMBER, 1979



TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 2000 KM SCOTT BASE MIDPOINT
JAN-MAR & OCT-DEC, 1979 SSN: 172 (AVG)

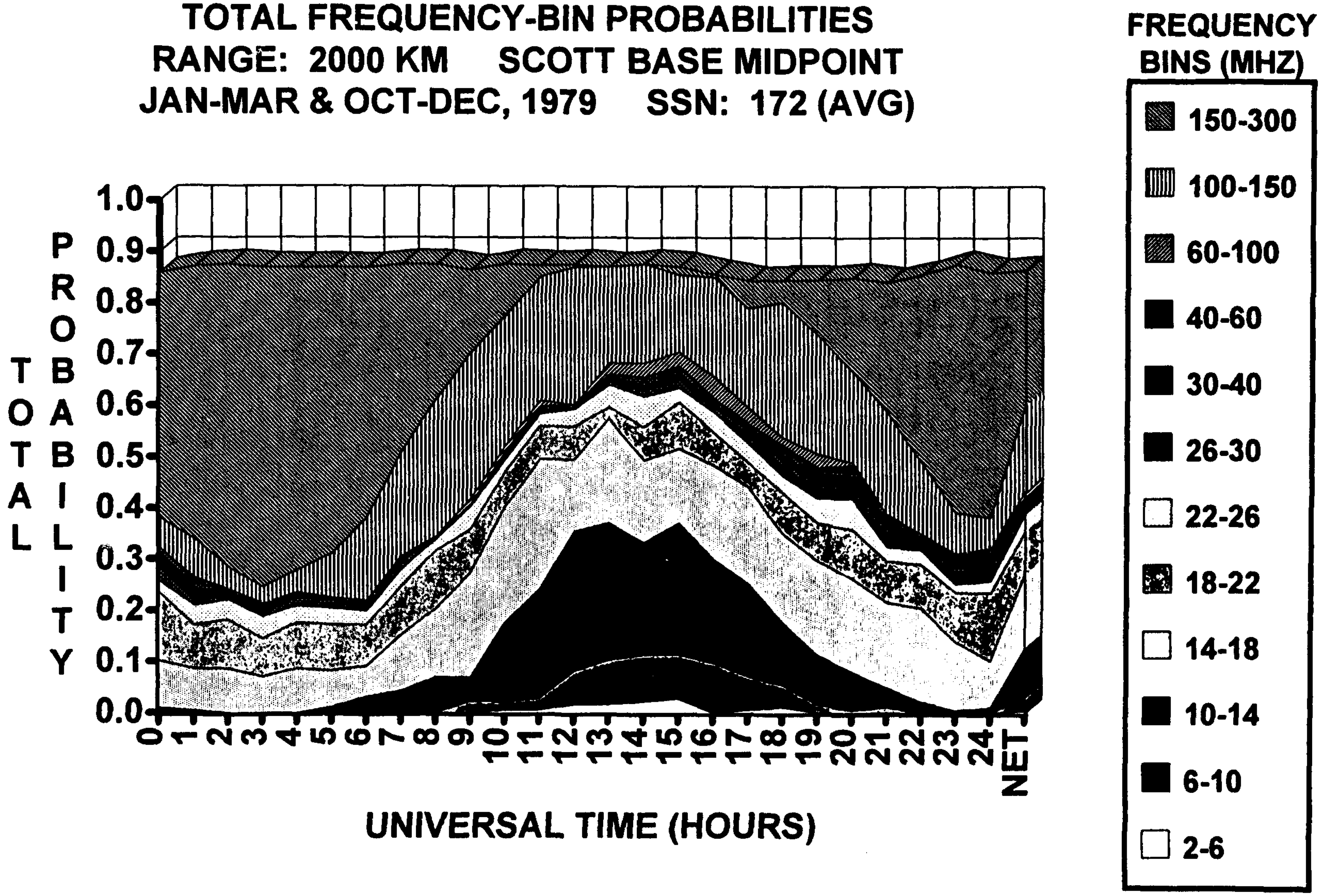
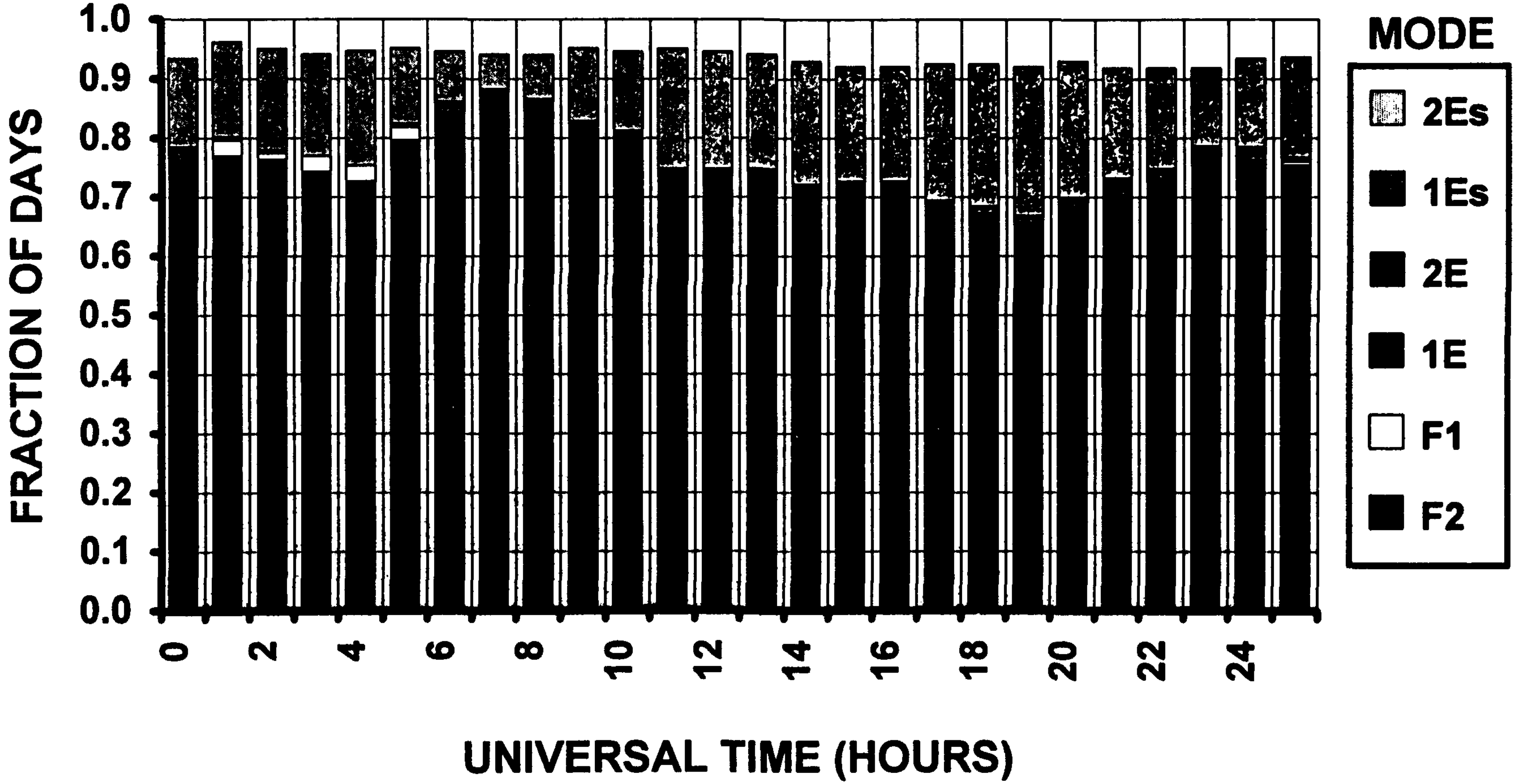


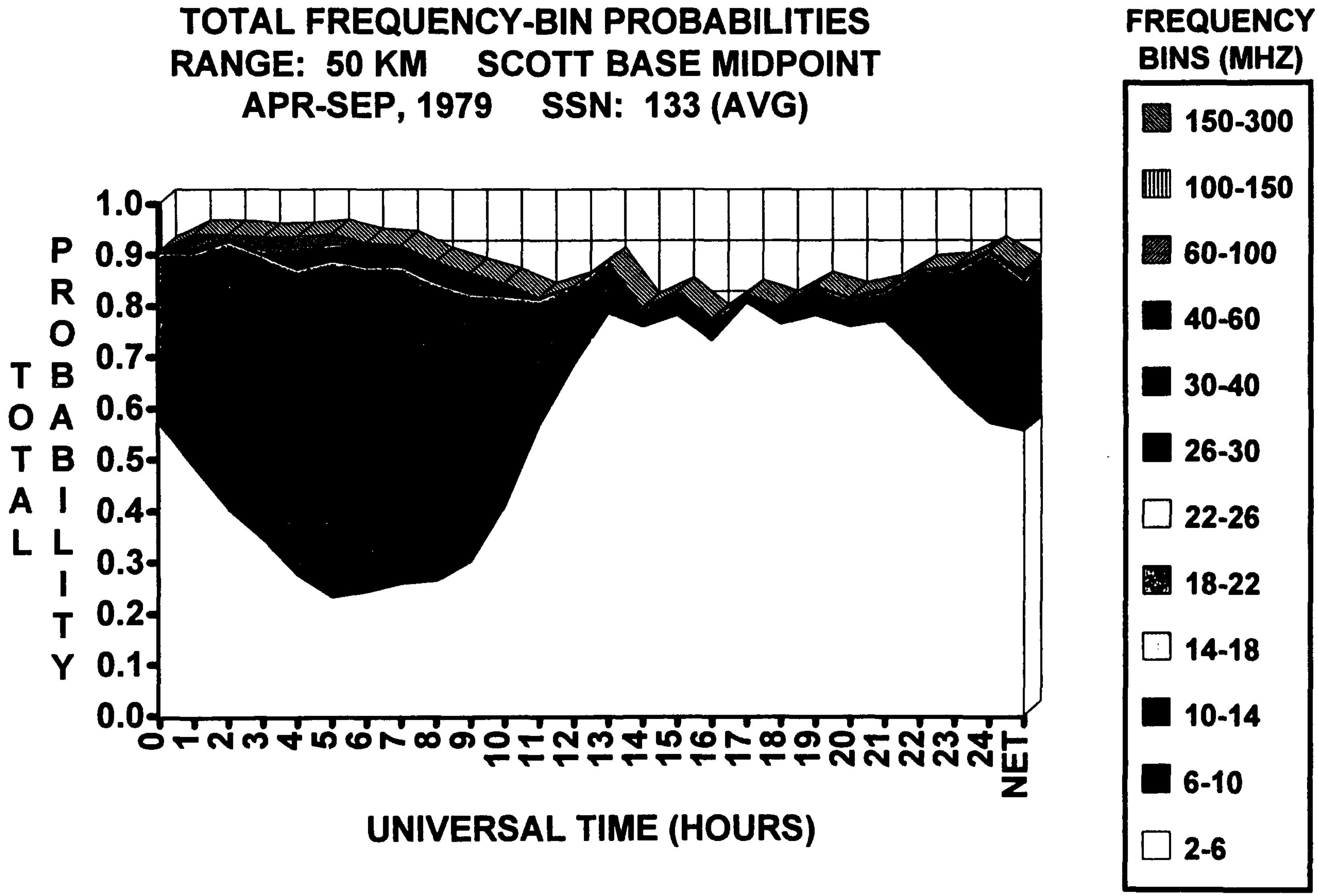
TABLE C.5 INDEX TO FREQUENCY DENSITY PLOTS

YEAR	PLOT	JAN-MAR & OCT-DEC (MAXIMUM SUN) RANGE (KM)	JAN-MAR & OCT-DEC (MAXIMUM SUN) PAGE NOS.	APR-SEP (MINIMUM SUN) RANGE (KM)	APR-SEP (MINIMUM SUN) PAGE NO.
1975	MODES	50	C-4	50	C-13
		200	C-6	200	C-15
		1000	C-8	1000	C-17
		2000	C-10	2000	C-19
	FREQ. DENSITY	50	C-5	50	C-14
		200	C-7	200	C-16
		1000	C-9	1000	C-18
		2000	C-11	2000	C-20
1979	MODES	50	C-22	50	C-31
		200	C-24	200	C-33
		1000	C-26	1000	C-35
		2000	C-28	2000	C-37
	FREQ. DENSITY	50	C-23	50	C-32
		200	C-25	200	C-34
		1000	C-27	1000	C-36
		2000	C-29	2000	C-38

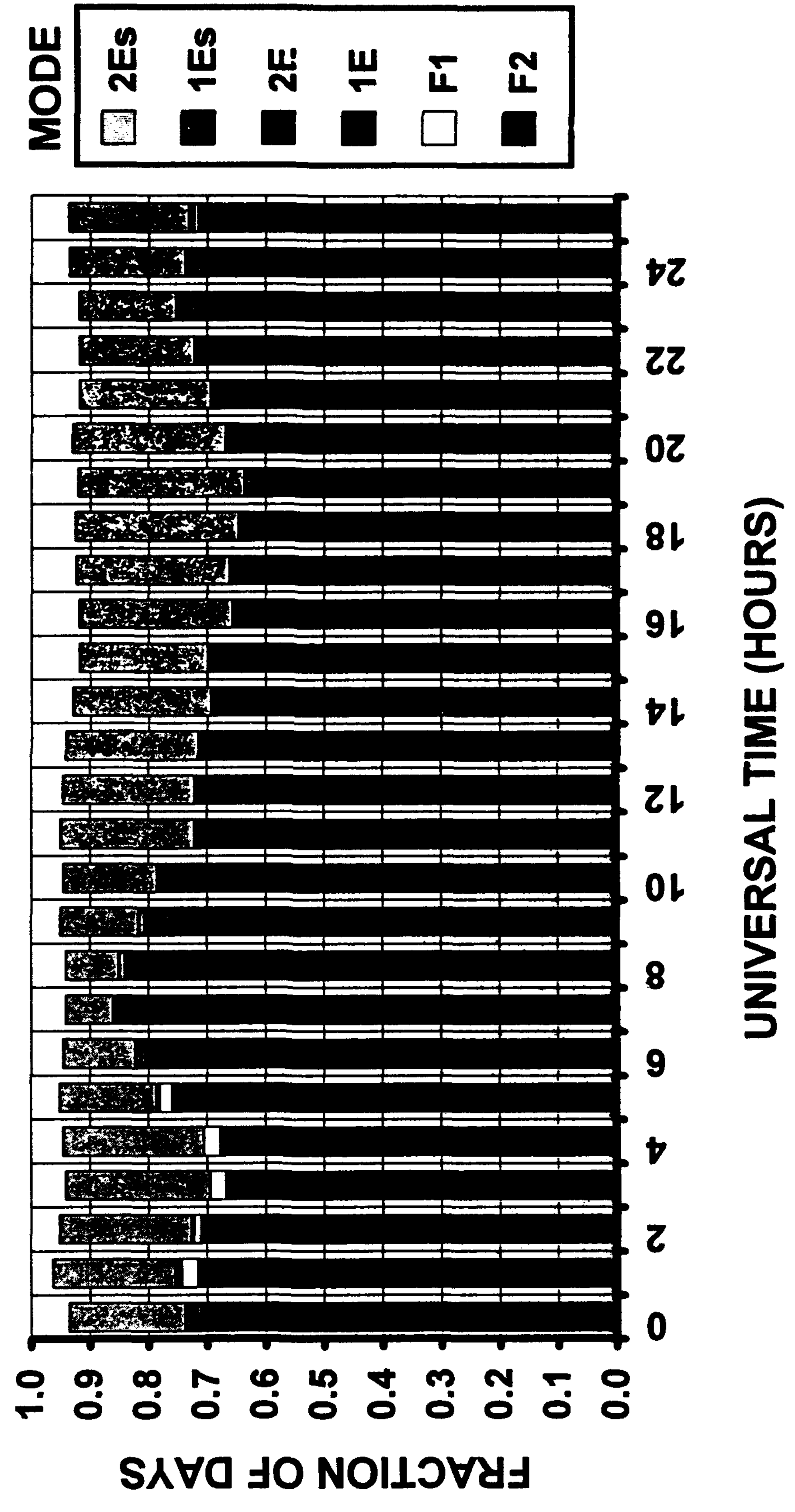
PROPAGATION MODE AVAILABILITY: 50-KM LINK
APRIL-SEPTEMBER, 1979



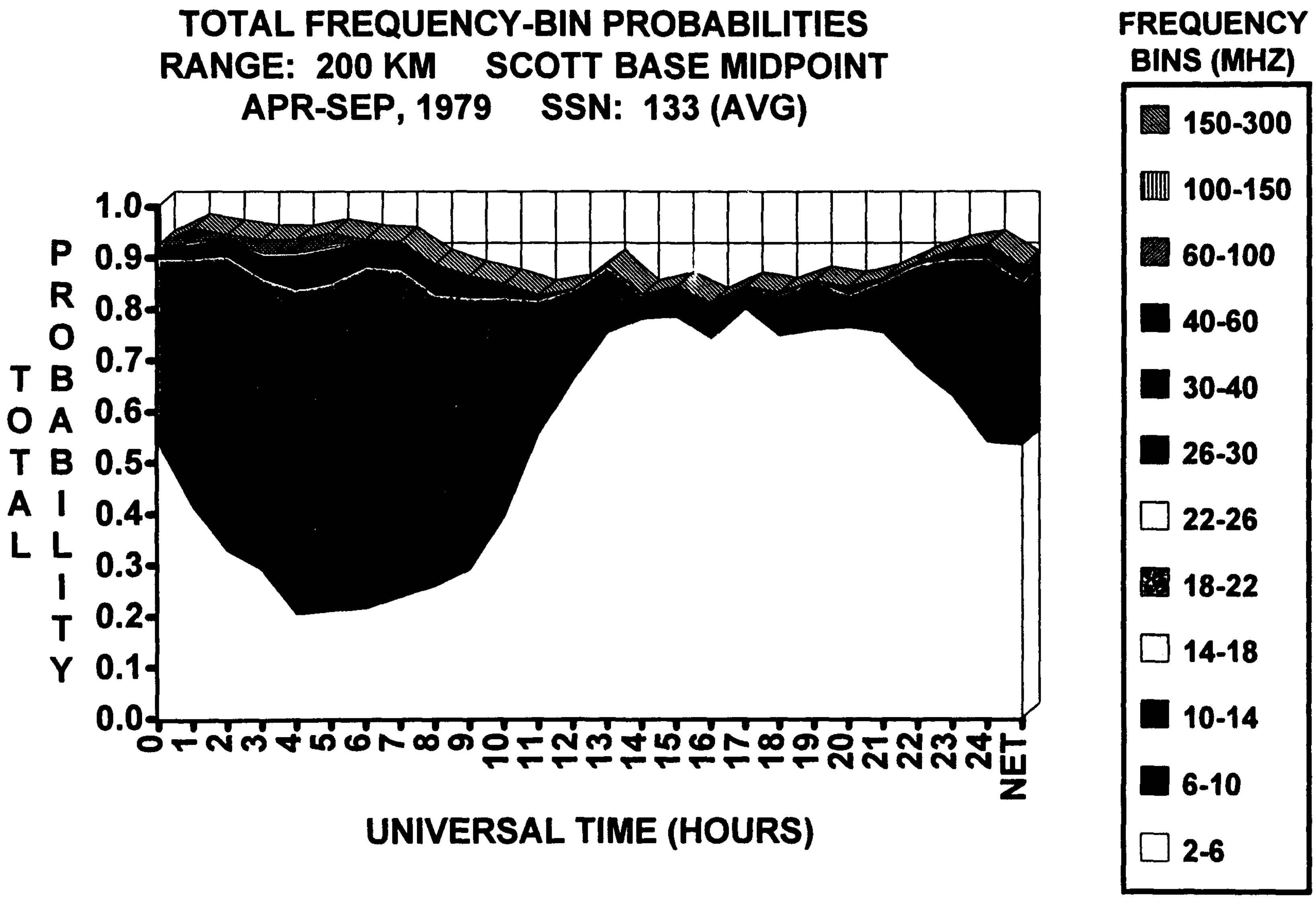
TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 50 KM SCOTT BASE MIDPOINT
APR-SEP, 1979 SSN: 133 (AVG)

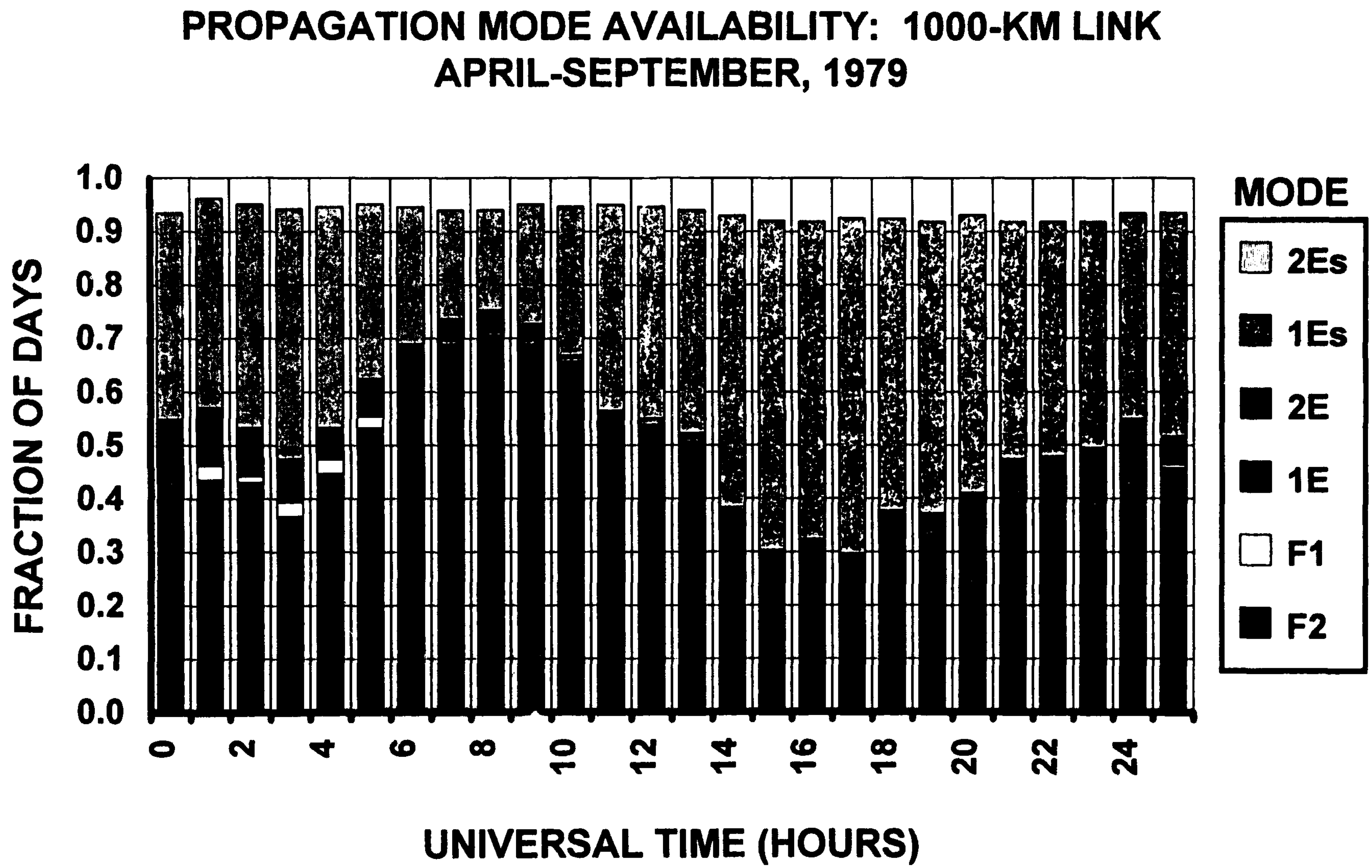


PROPAGATION MODE AVAILABILITY: 200-KM LINK
APRIL-SEPTEMBER, 1979

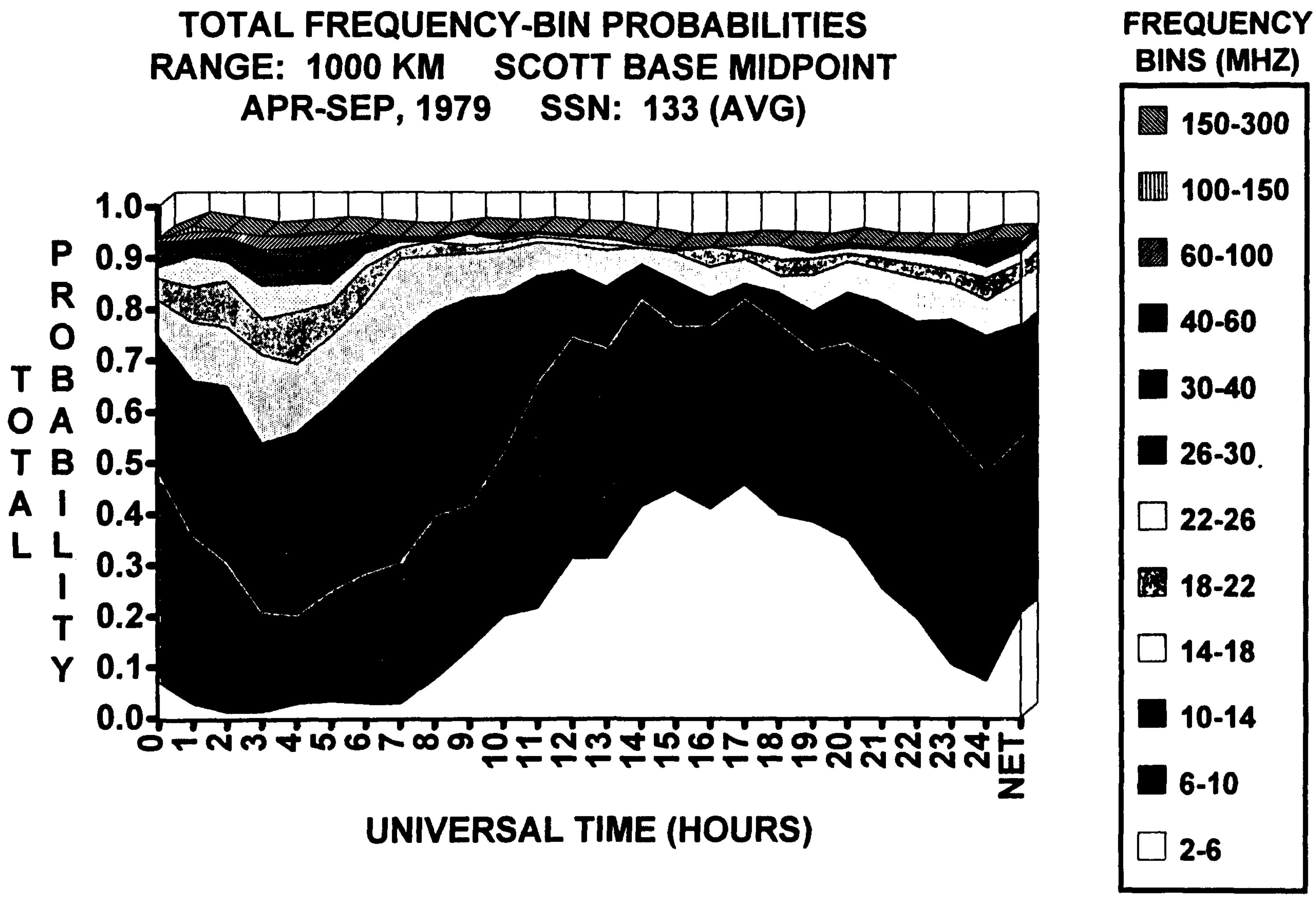


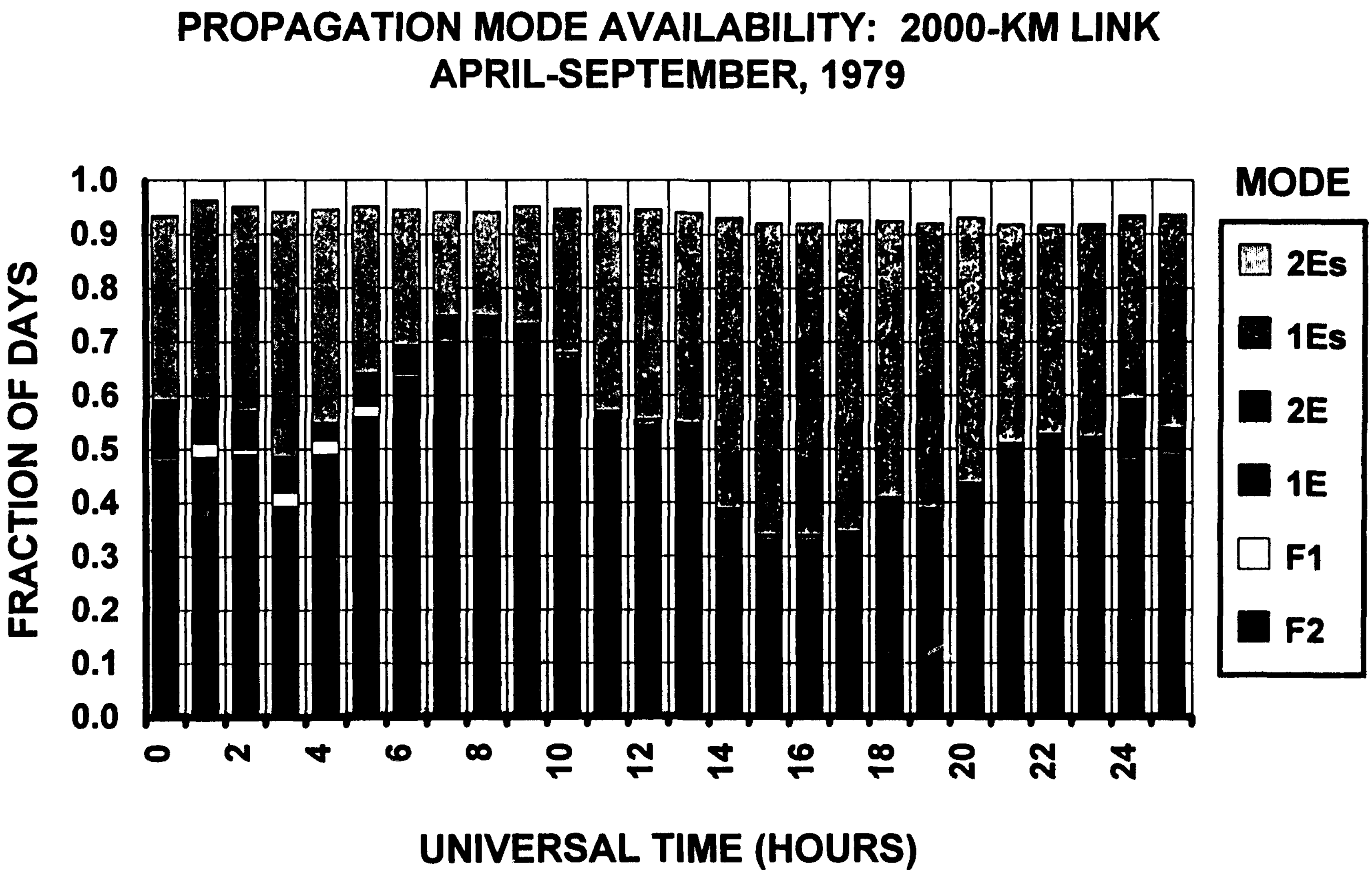
TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 200 KM   SCOTT BASE MIDPOINT
APR-SEP, 1979   SSN: 133 (AVG)

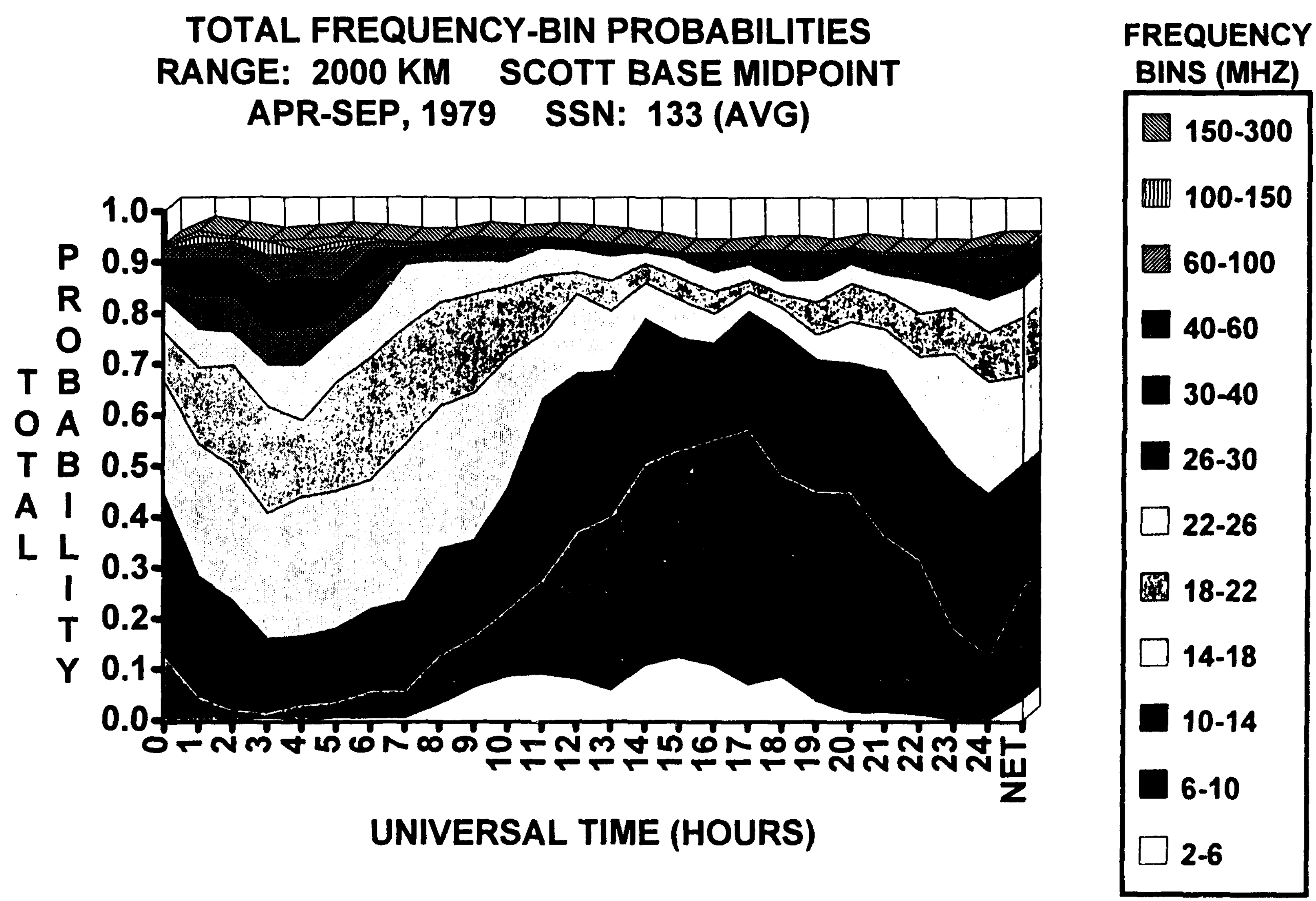



PROPAGATION MODE AVAILABILITY: 1000-KM LINK
APRIL-SEPTEMBER, 1979
FRACTION OF DAYS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
20
22
24
UNIVERSAL TIME (HOURS)
MODE
2Es
1Es
2E
1E
F1
F2

TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 1000 KM SCOTT BASE MIDPOINT
APR-SEP, 1979 SSN: 133 (AVG)




PROPAGATION MODE AVAILABILITY: 2000-KM LINK
APRIL-SEPTEMBER, 1979
FRACTION OF DAYS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
20
22
24
UNIVERSAL TIME (HOURS)
MODE
2Es
1Es
2E
1E
F1
F2


TOTAL FREQUENCY-BIN PROBABILITIES
RANGE: 2000 KM SCOTT BASE MIDPOINT
APR-SEP, 1979 SSN: 133 (AVG)
TOTAL PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 NET
UNIVERSAL TIME (HOURS)
FREQUENCY BINS (MHZ)
150-300
100-150
60-100
40-60
30-40
26-30
22-26
18-22
14-18
10-14
6-10
2-6

APPENDIX D IONOSONDE MEASUREMENT-PREDICTION COMPARISON

This appendix contains the results of a measurement-prediction comparison performed using standard MUF values for oblique HF links of 50-, 200-, 1000-, and 2000-km ranges. The table on the following page indexes results for the minimum, average, and maximum sunspot numbers found over the 14 years from 1970 to 1983 in each of the four months of March, June, September, and December.

		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

The results for each month and SSN value (min, avg, or max) are preceded in the appendix by this table with the corresponding block of the table highlighted. The four months correspond to different values of solar zenith angles. The sun produces much less ionospheric ionization in the months of June and September then in the months of March and December and much higher ionization with maximum than minimum sunspot number. The average SSN results are provided to show typical values. The first row of the table (highlighted below) corresponds to the minimum sunspot numbers found in the years 1970 to 1983 in the months March, June, September, and December. The minimum SSN value in March was determined from daily values to be 15. In June, this minimum value was 24. Minimum SSN values were 14 in September and 17 in December.

		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 / 1975	D-49 to D-52	14 / 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

The average SSN values for March, June, September, and December are 79 (1978), 77 (1983), 63 (1972), and 86 (1971).

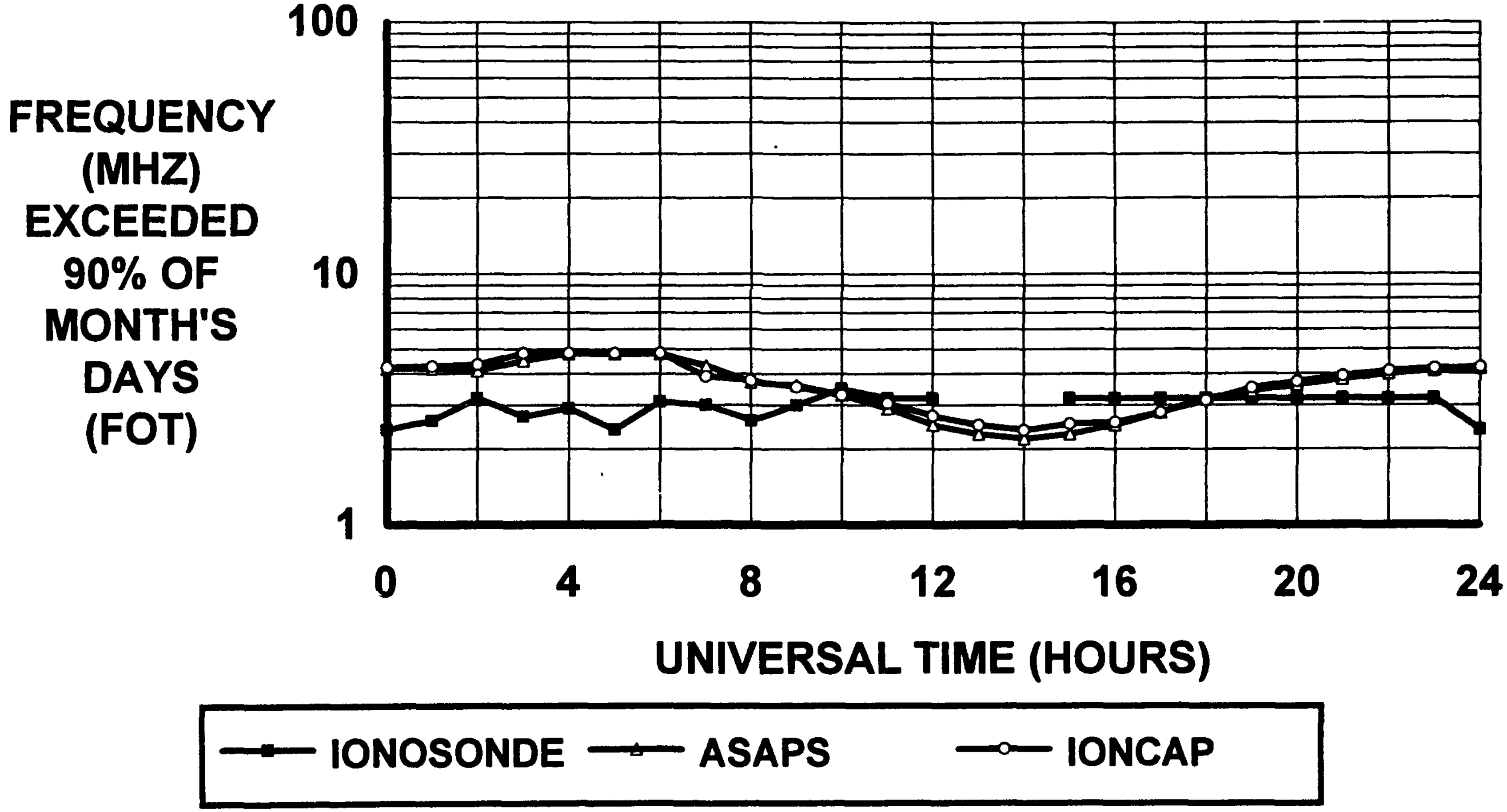
		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

The maximum SSN values for March, June, September, and December are 164 (1982), 151 (1981), 170 (1980), and 200 (1979).

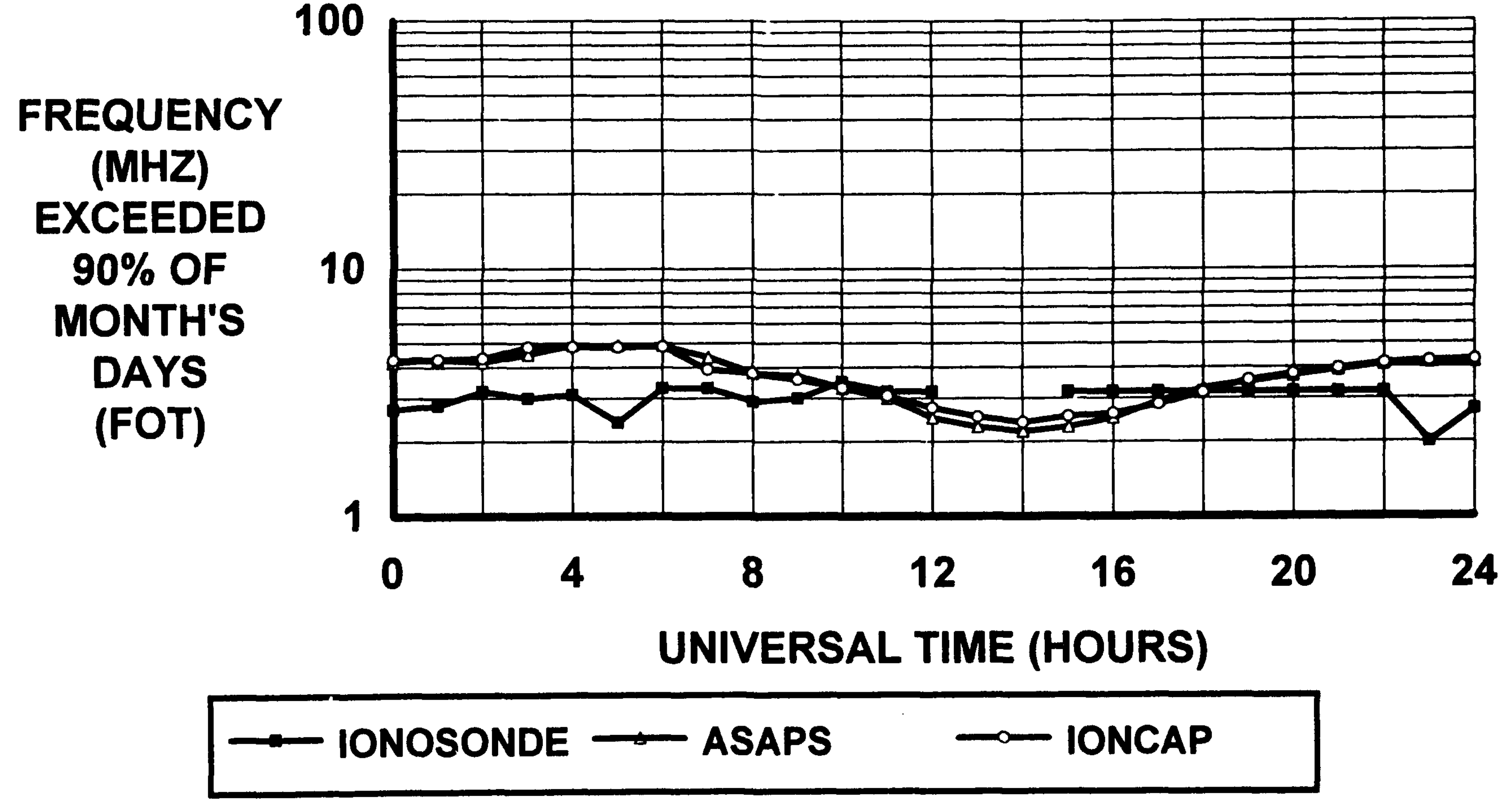
		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	7[illegible] / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	[illegible] / 1982	[illegible] to [illegible]	[illegible] / 1980	[illegible] to [illegible]	170 / 1981	[illegible] to [illegible]	200 / 1979	[illegible] to D-152
	MUF	[illegible] / 1982	[illegible] to [illegible]	[illegible] / 1980	[illegible] to [illegible]	[illegible] / 1981	[illegible] to [illegible]	[illegible] / 1979	[illegible] to [illegible]
	HPF	[illegible] / 1982	D-40 to [illegible]	[illegible] / 1980	[illegible] to D-82	170 / 1981	[illegible] to [illegible]	200 / 1979	[illegible] to D-160

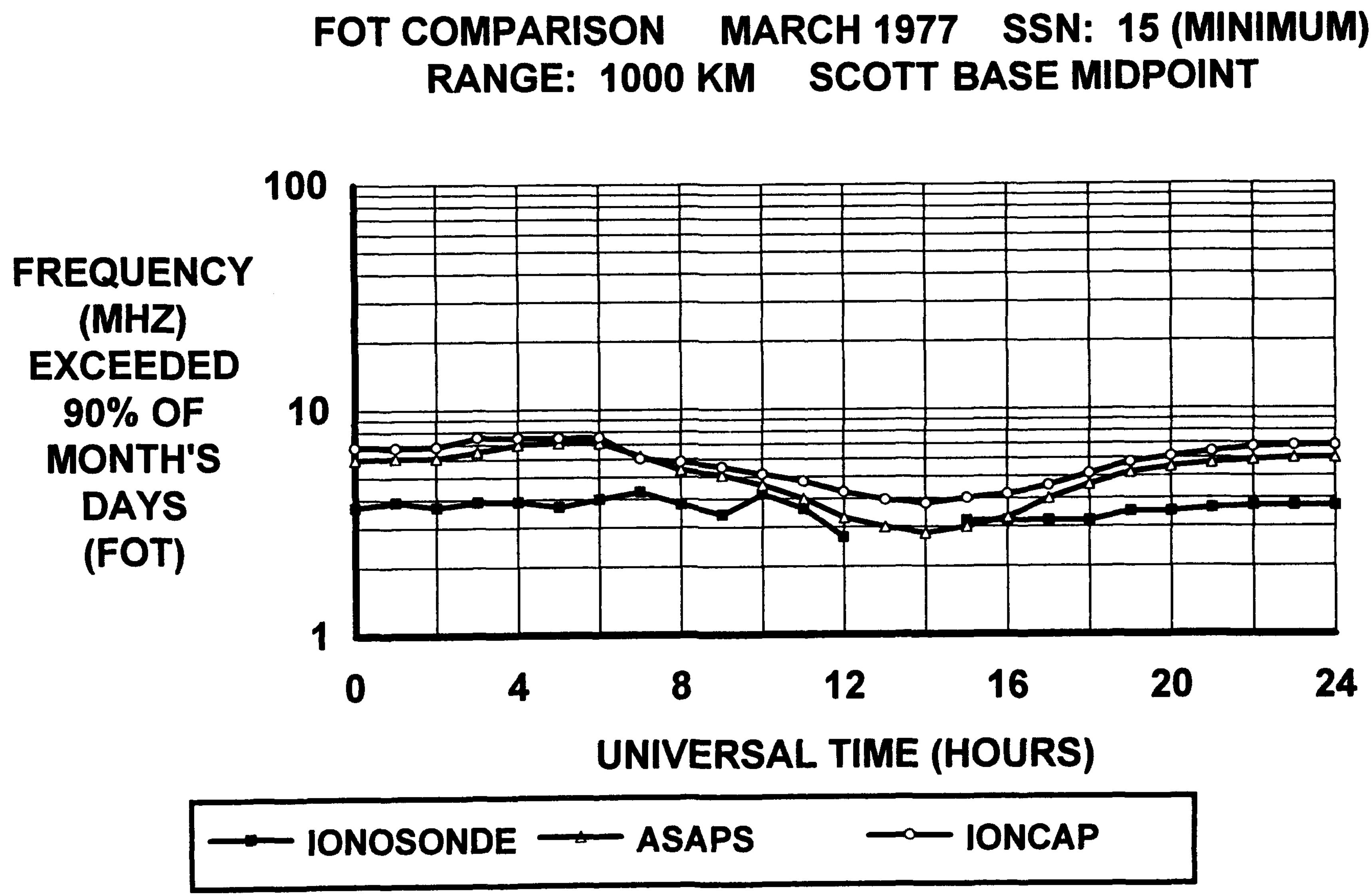
		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

FOT COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT

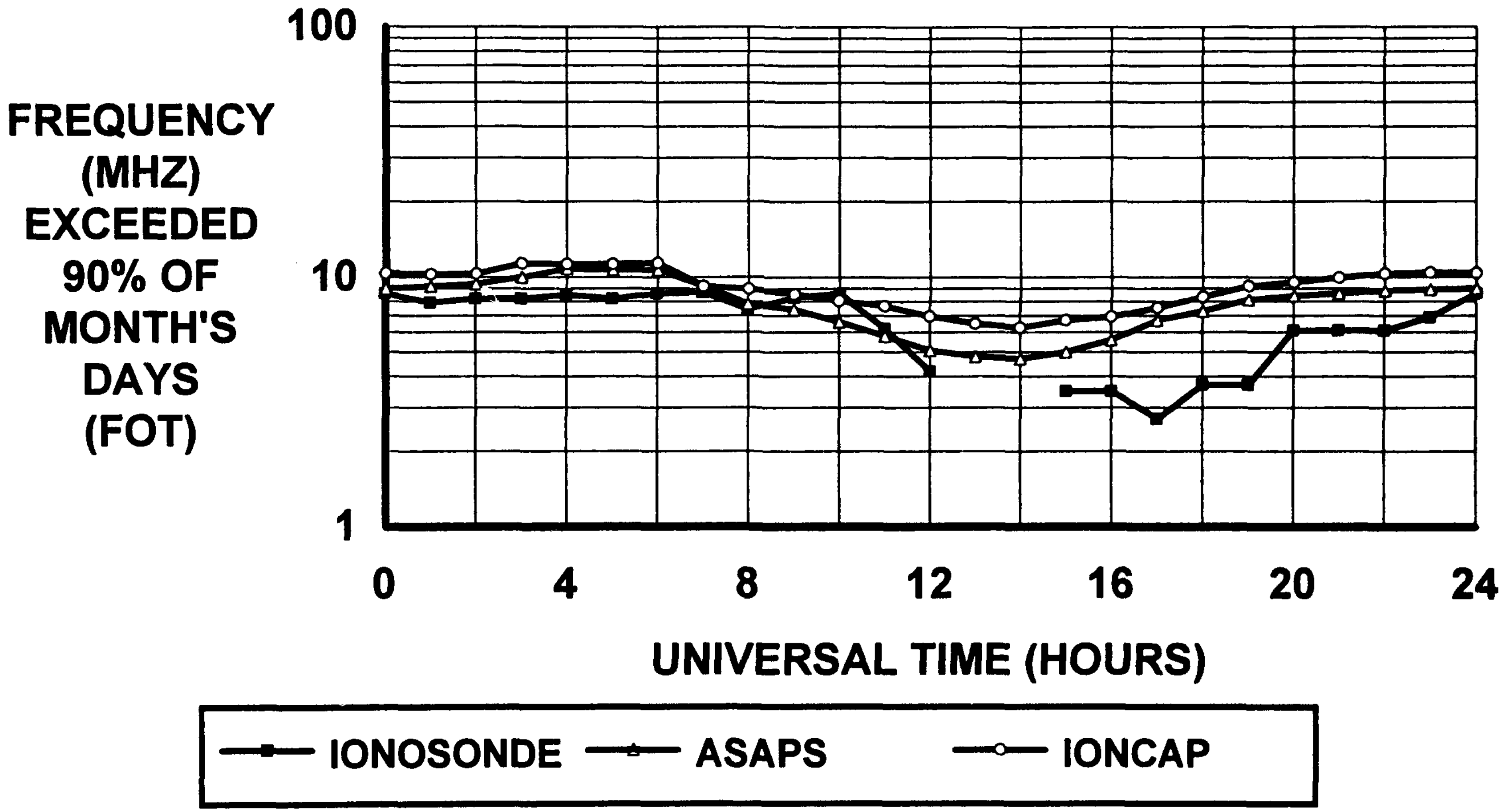


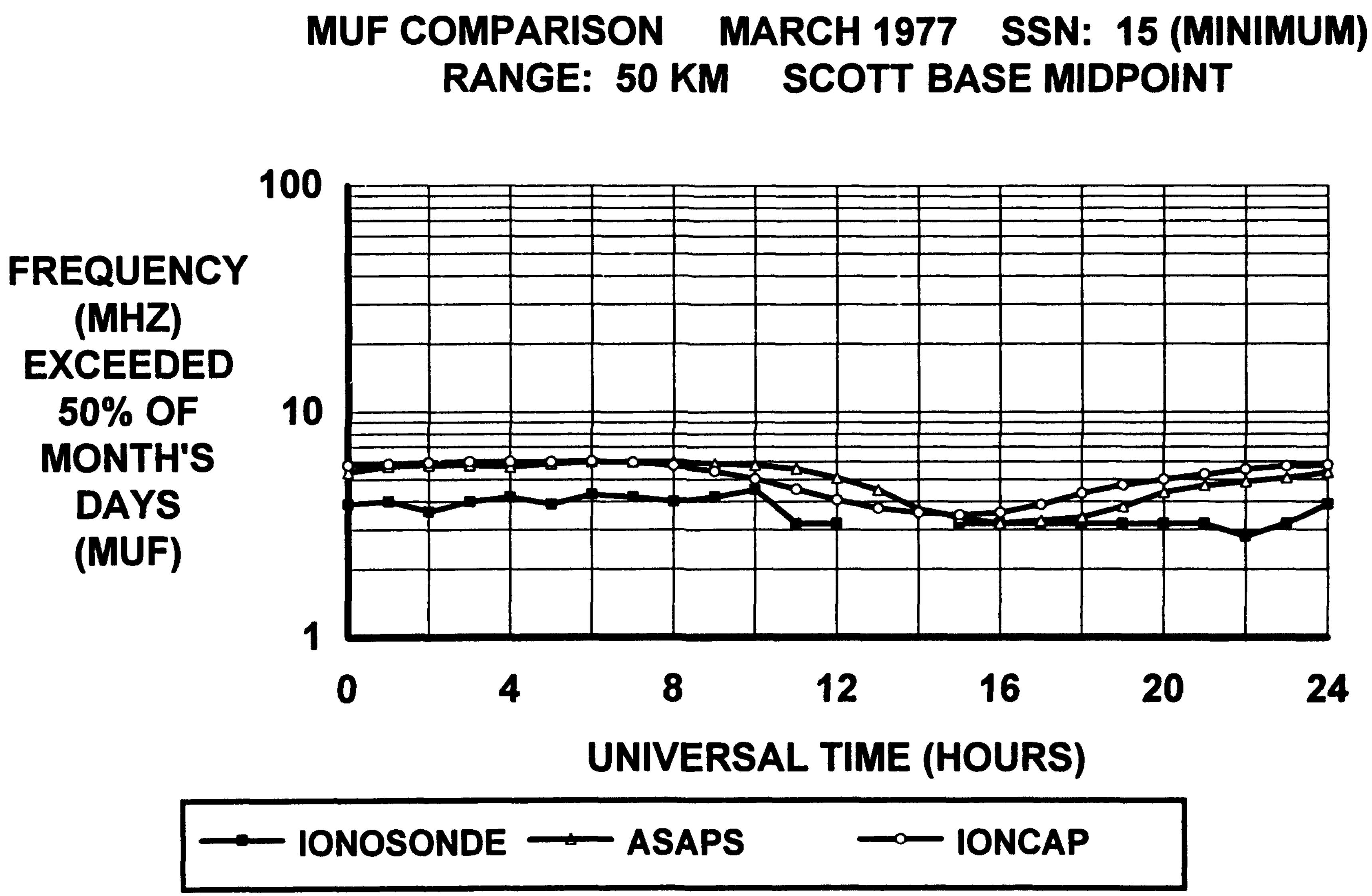
FOT COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT



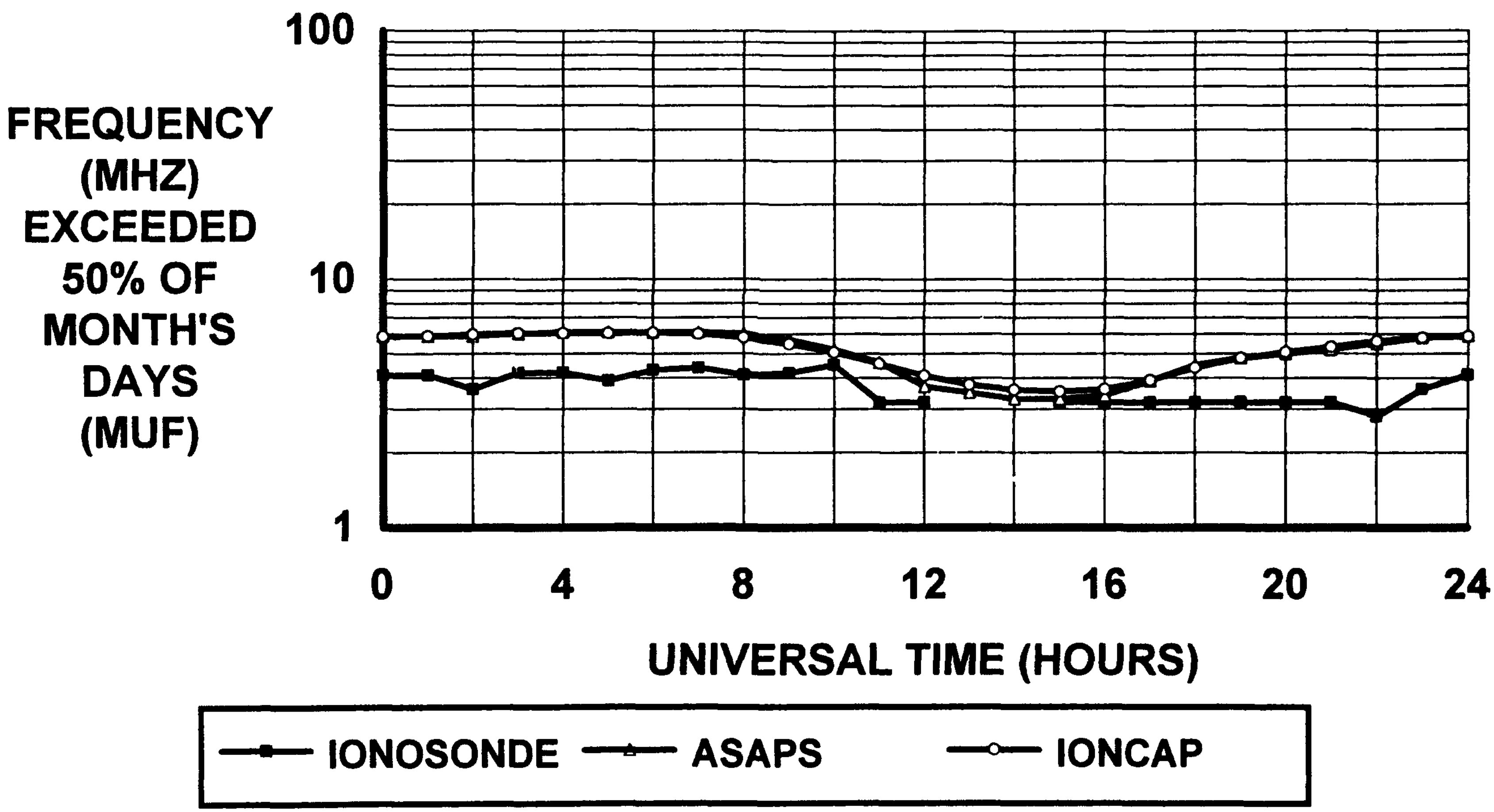

FOT COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

FOT COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT

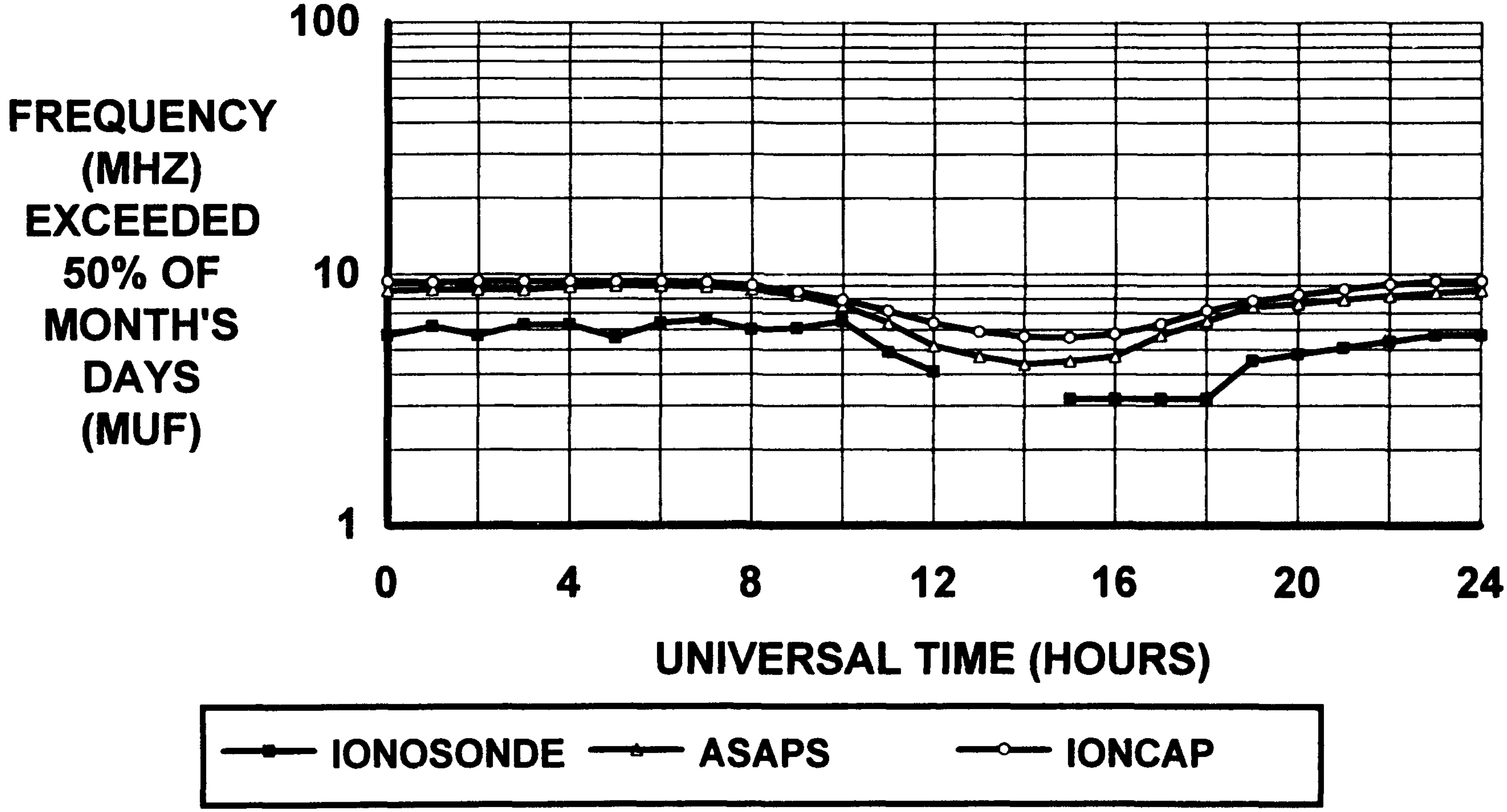



MUF COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

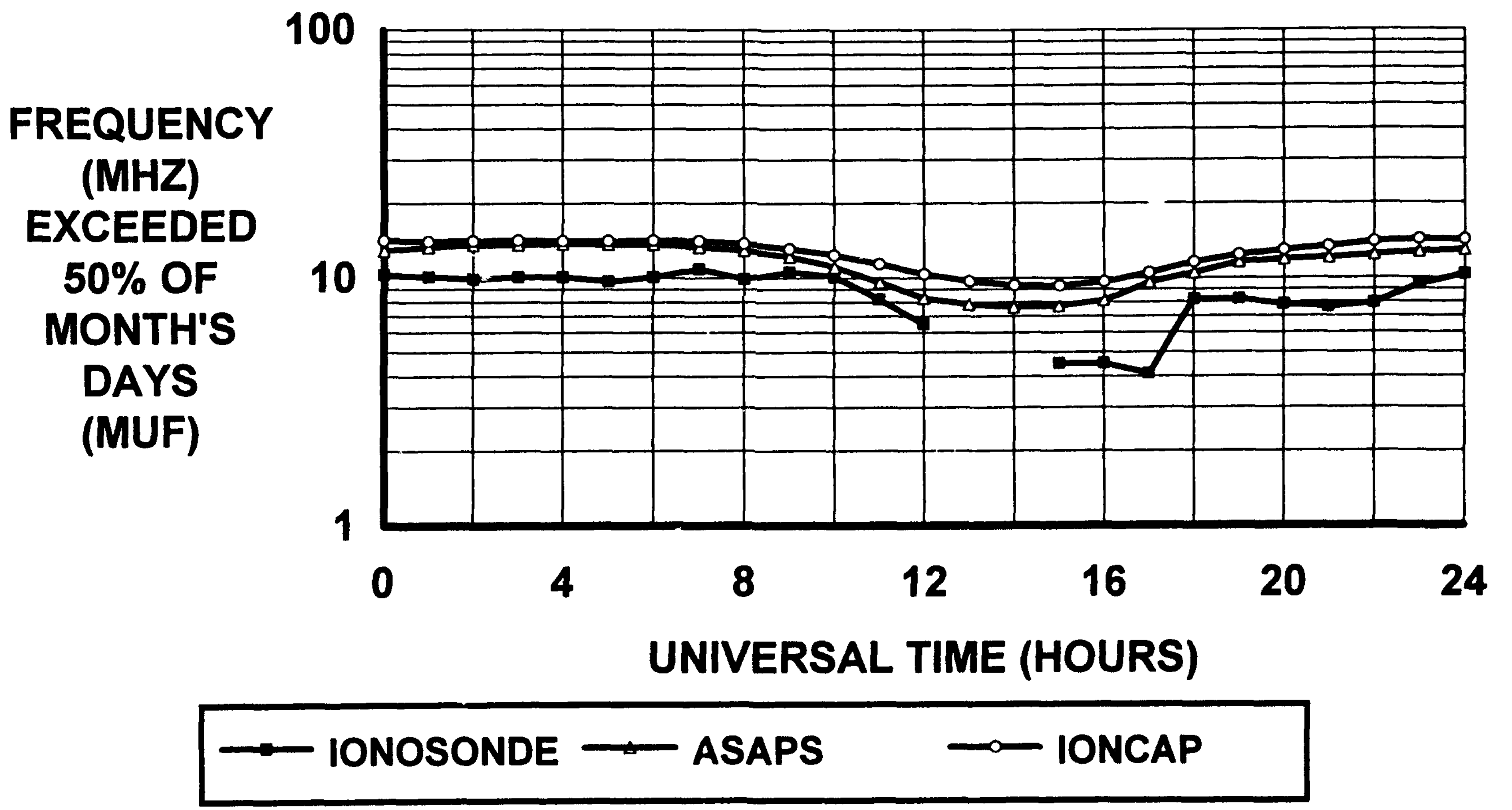
MUF COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT



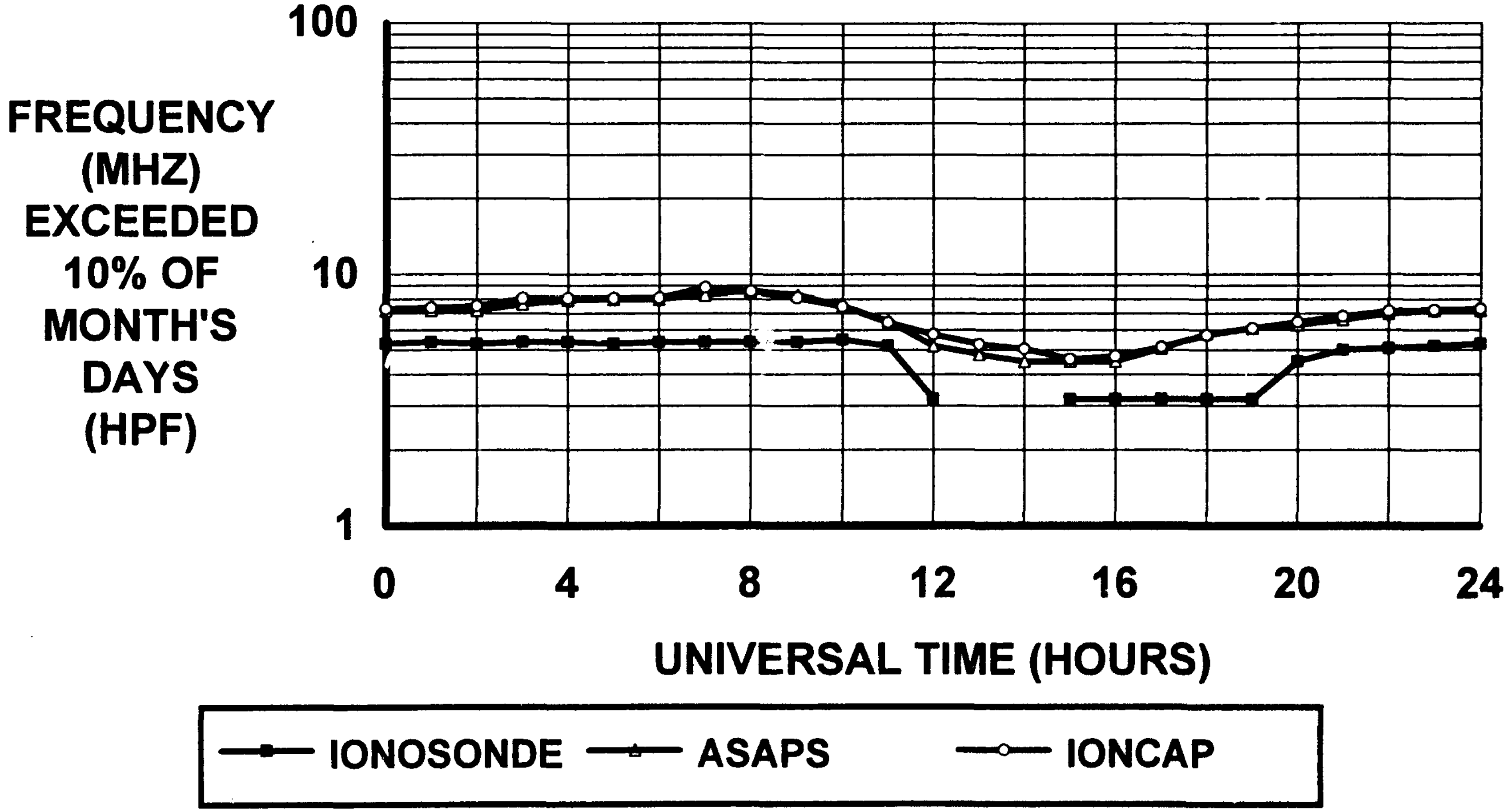
MUF COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT



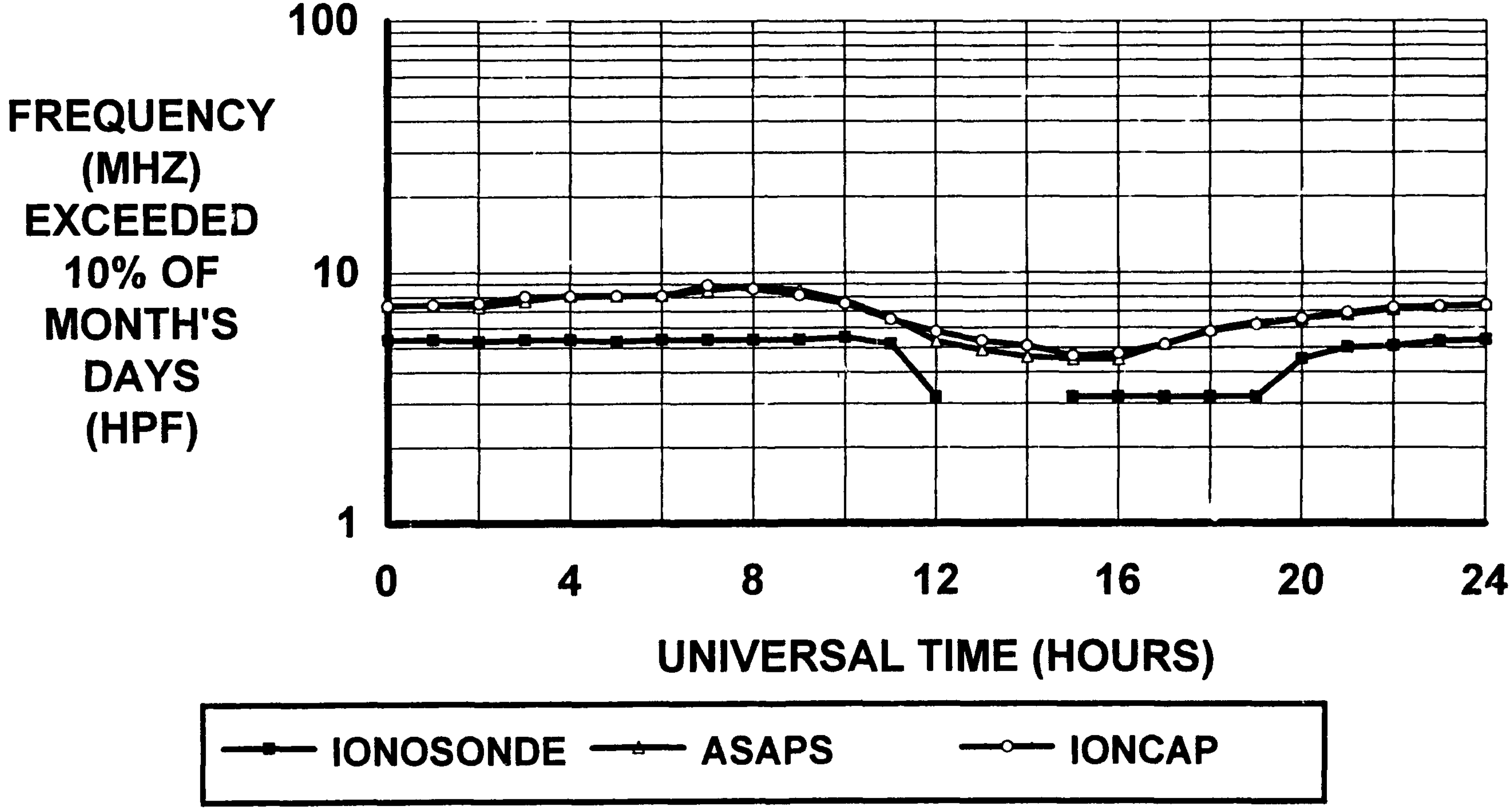
MUF COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT



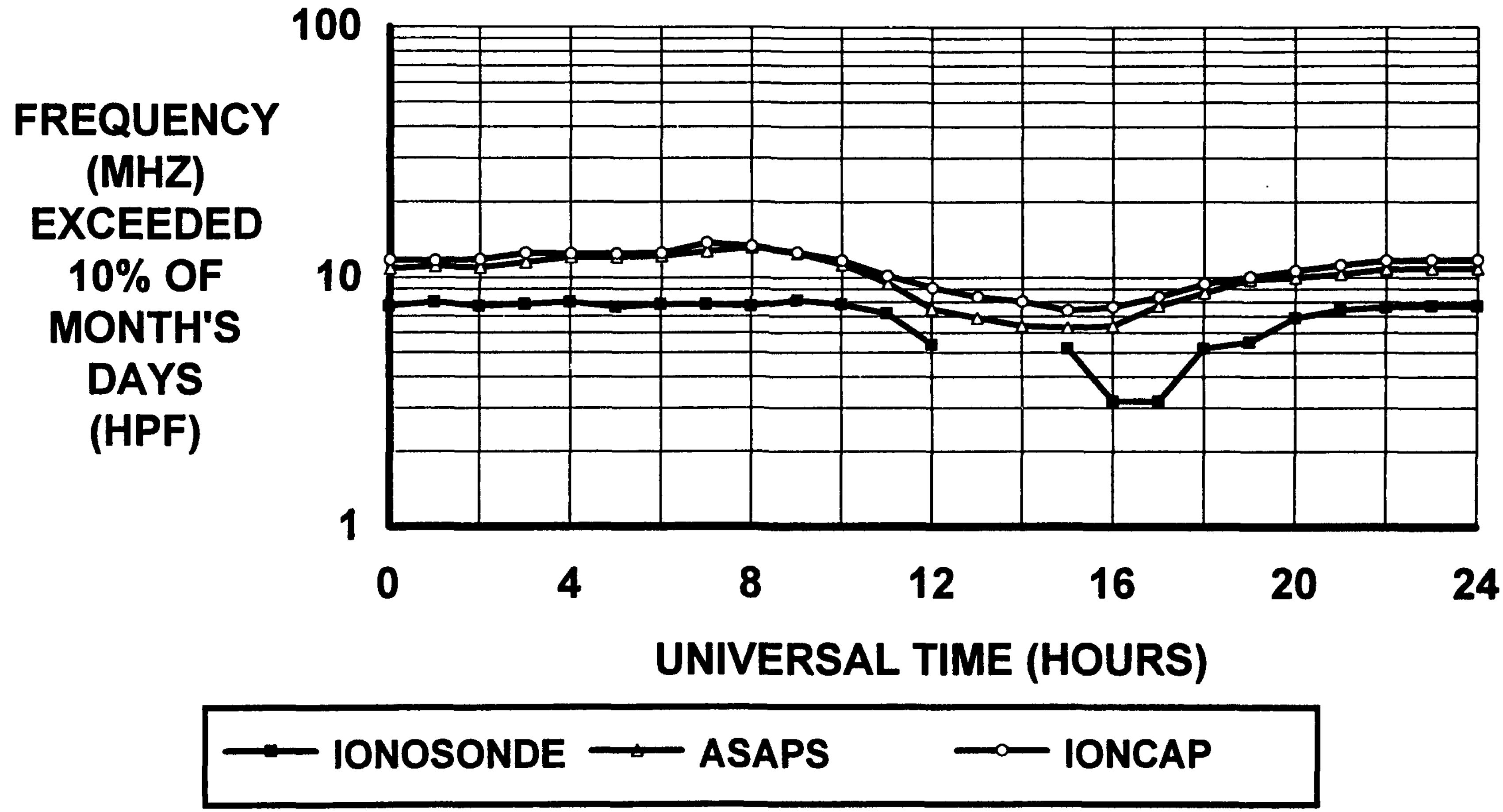
HPF COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT

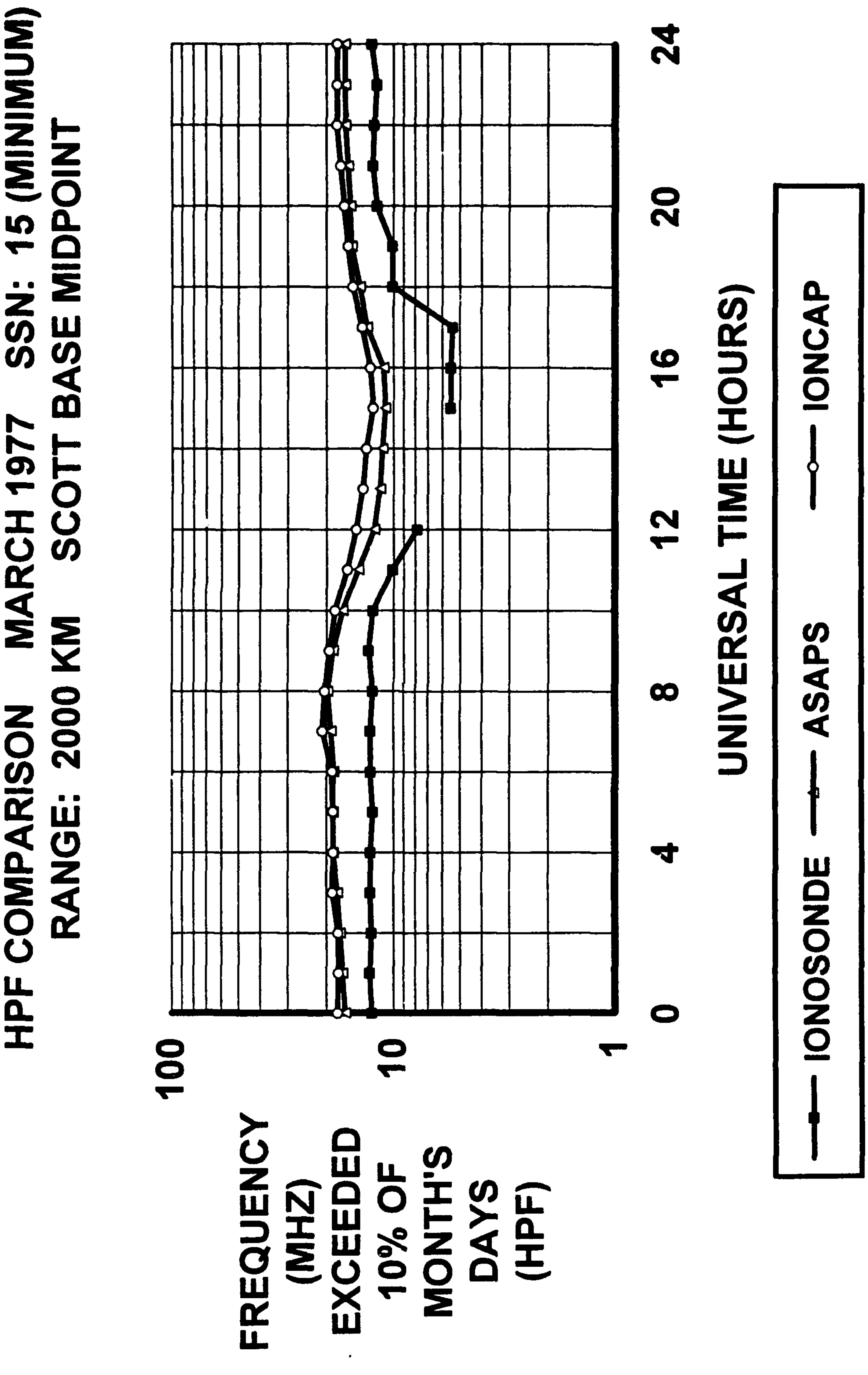


HPF COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT



HPF COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT

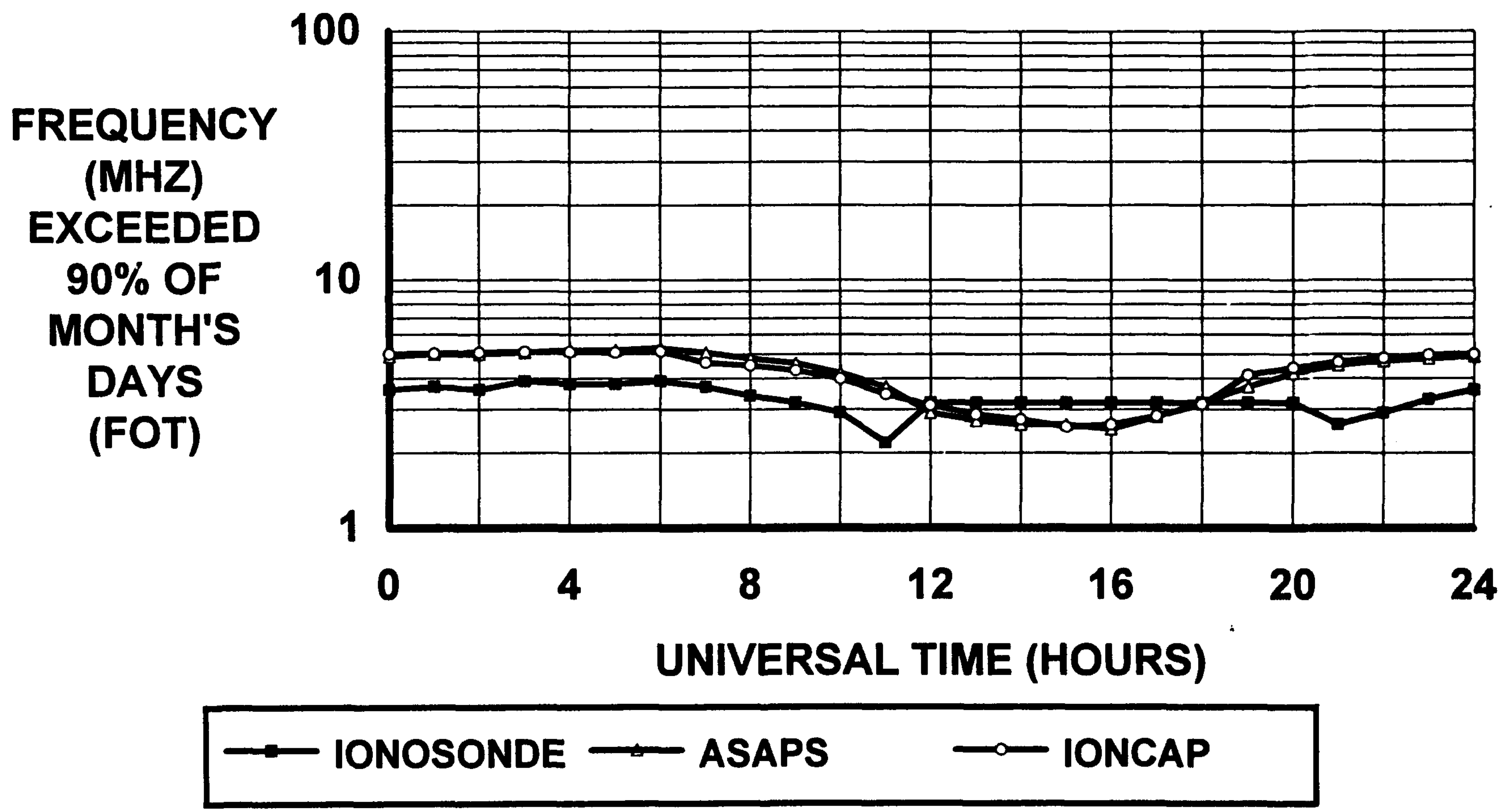




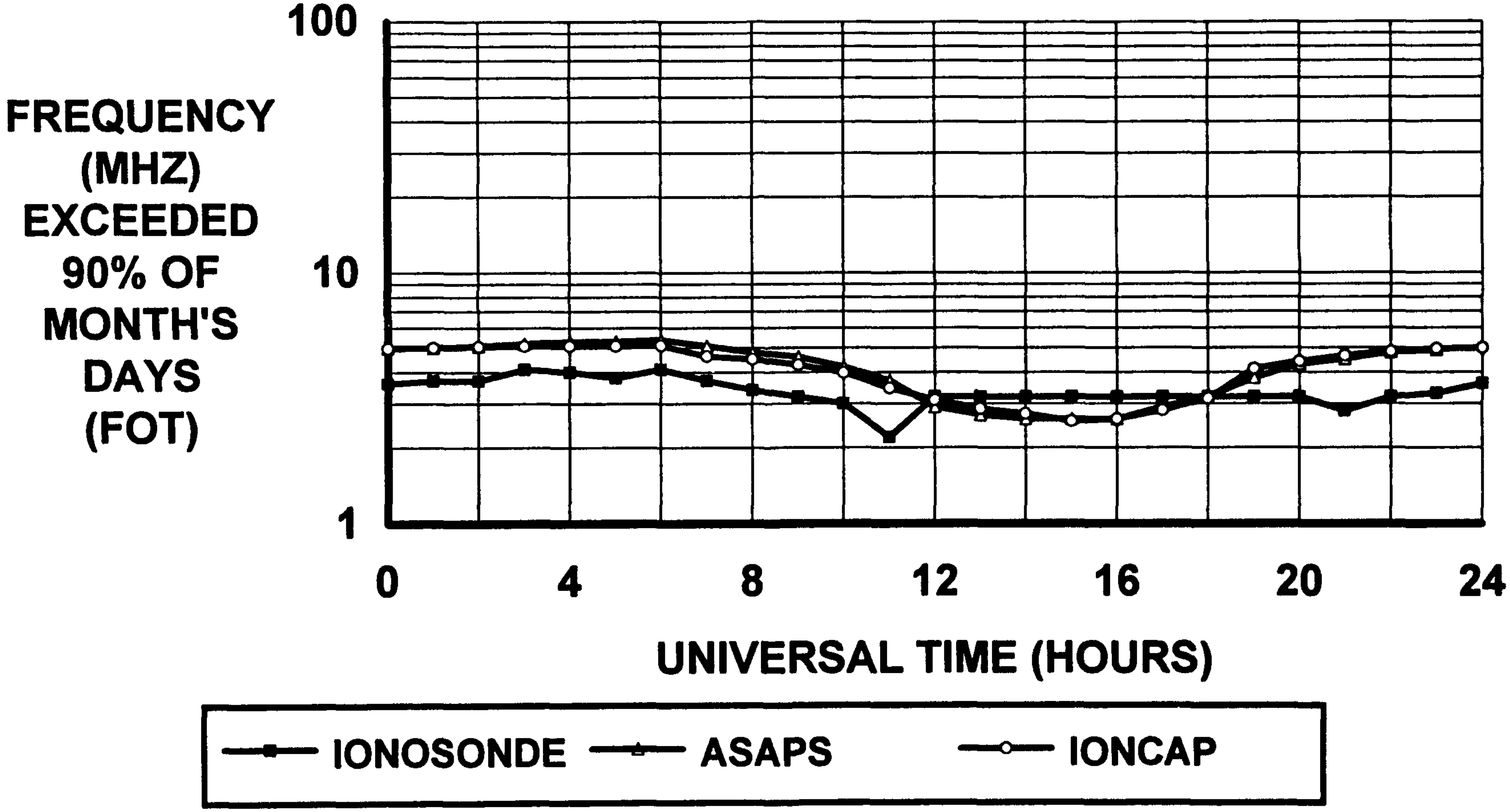
HPF COMPARISON MARCH 1977 SSN: 15 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

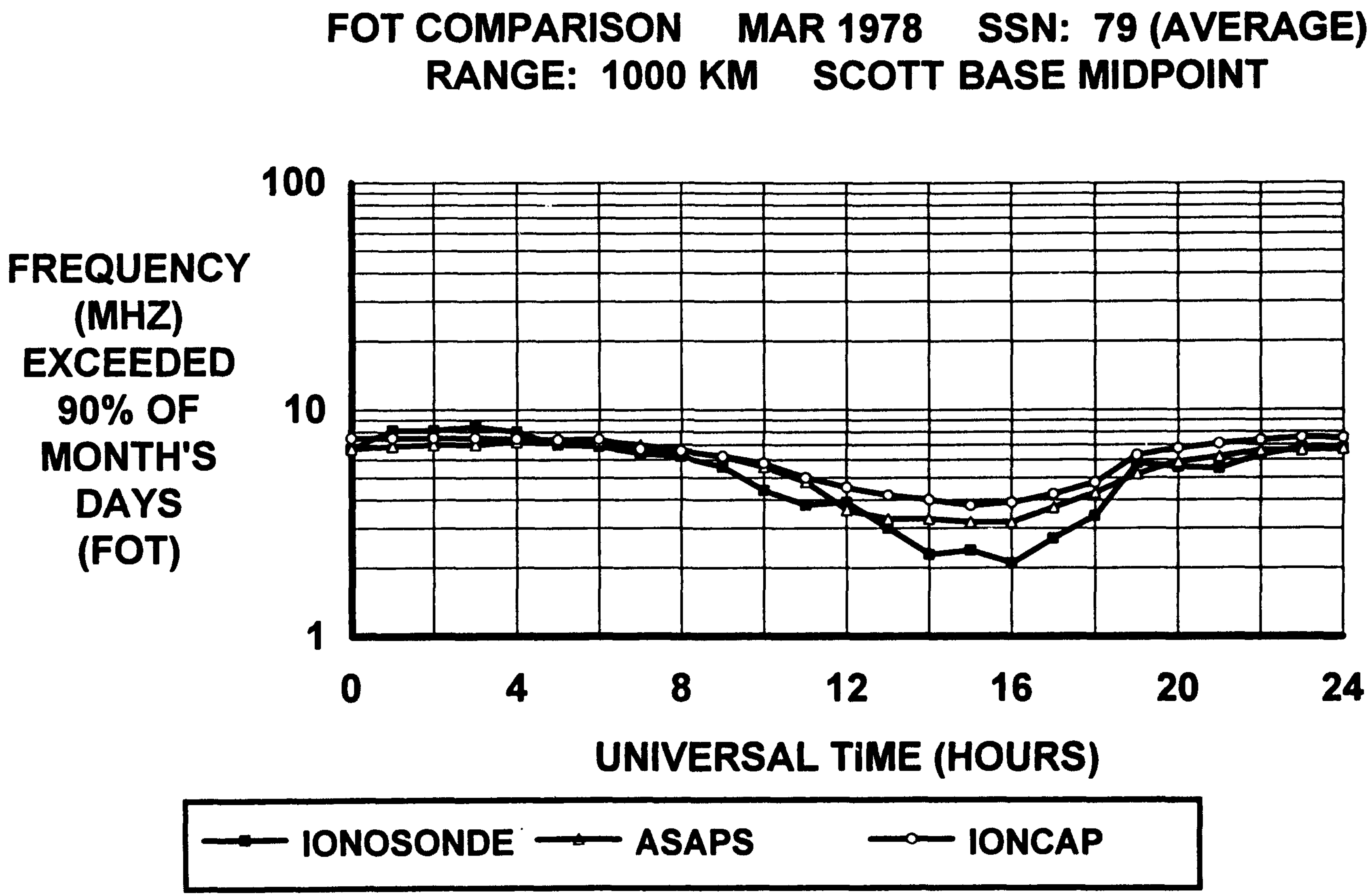
		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-28 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

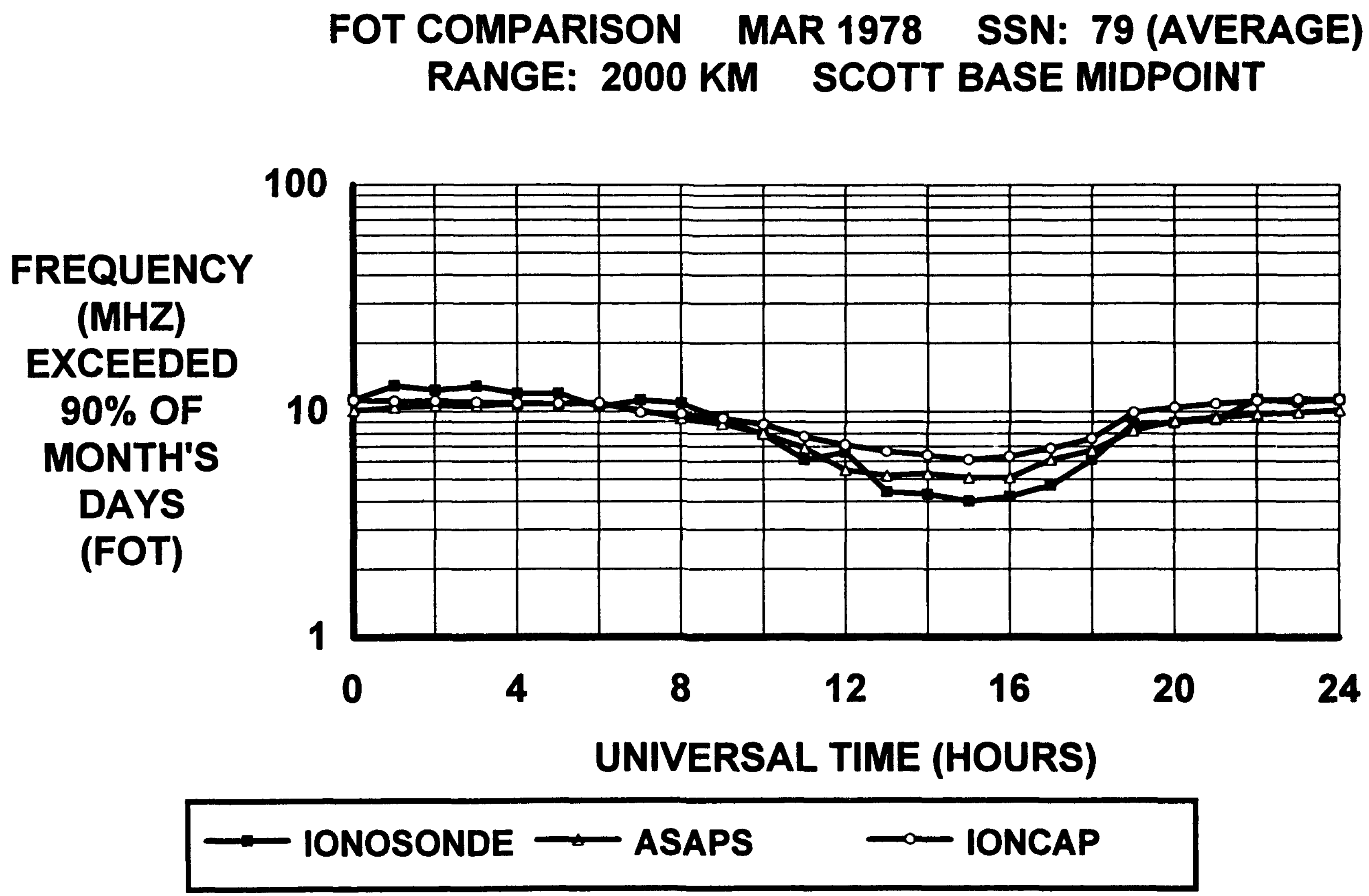
FOT COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT



FOT COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT

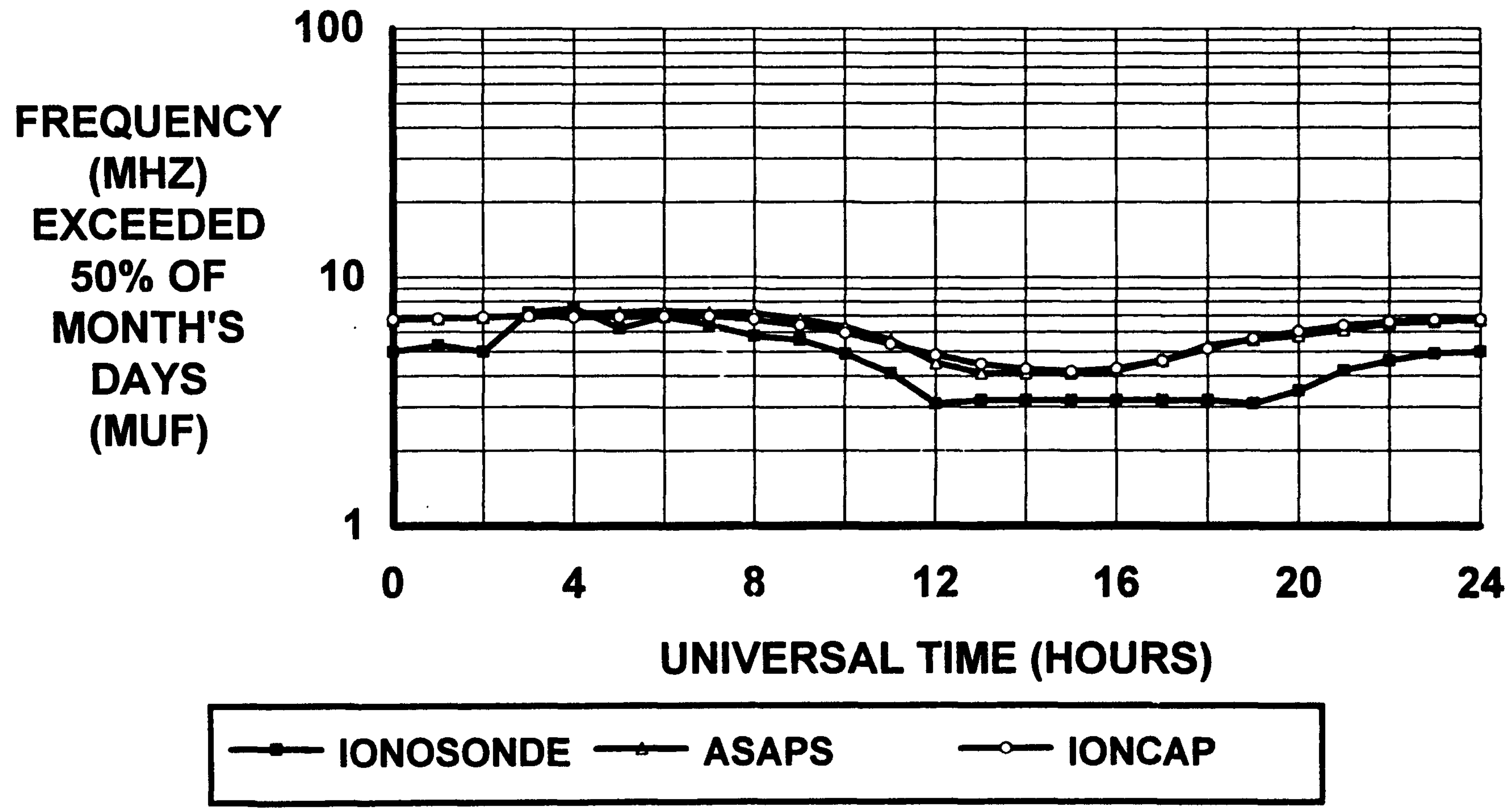


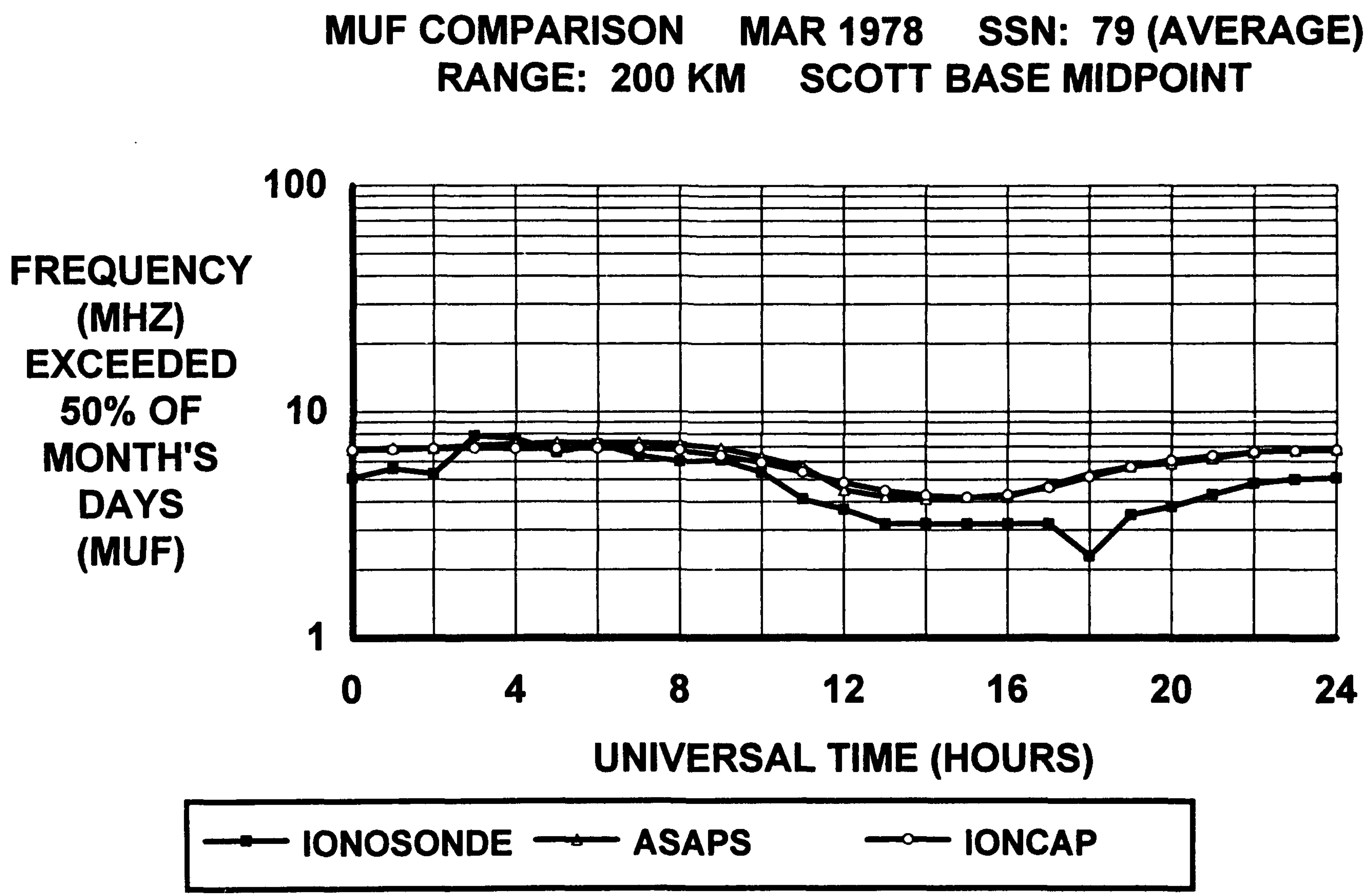

FOT COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

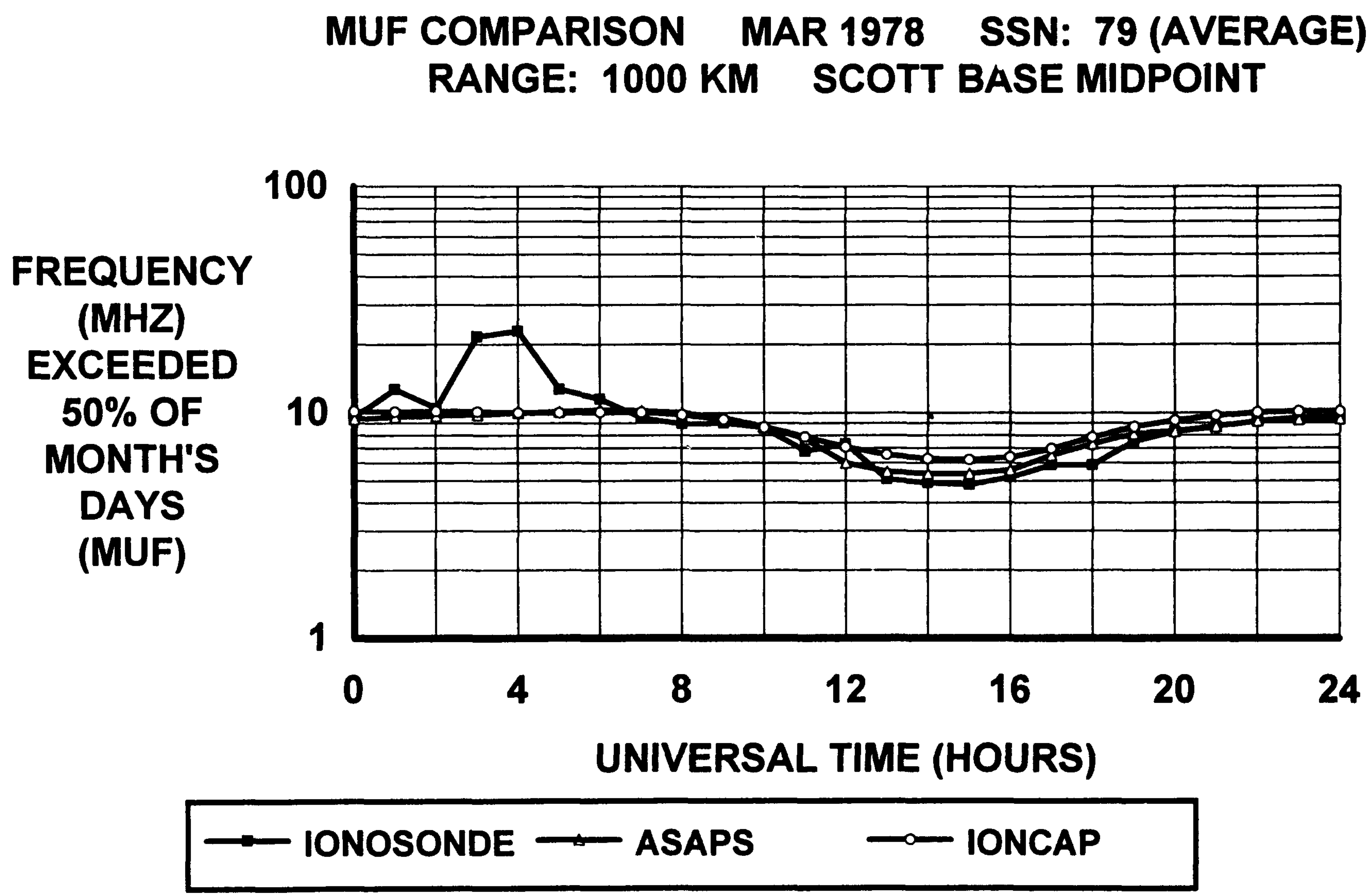


FOT COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

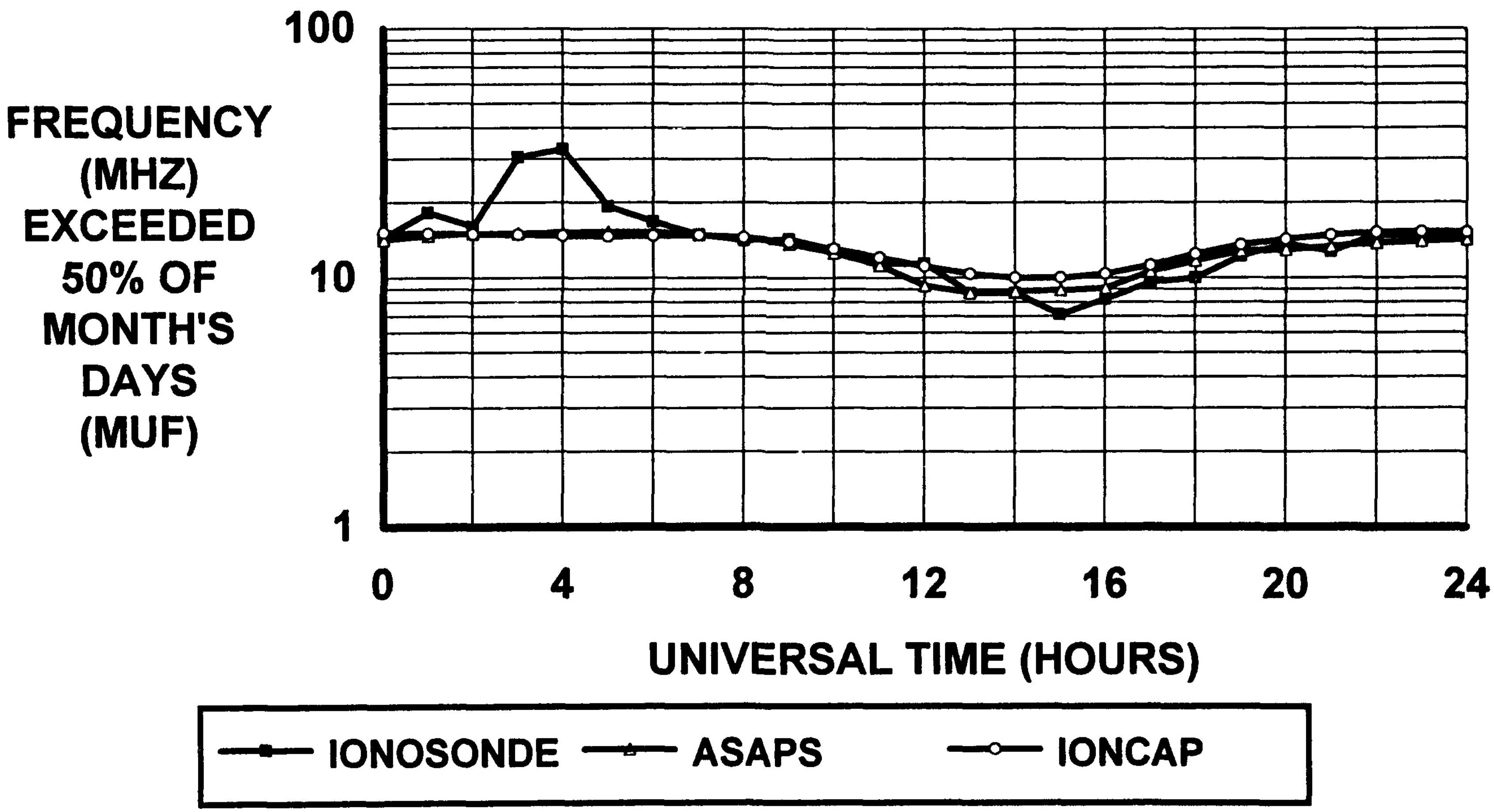
MUF COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT

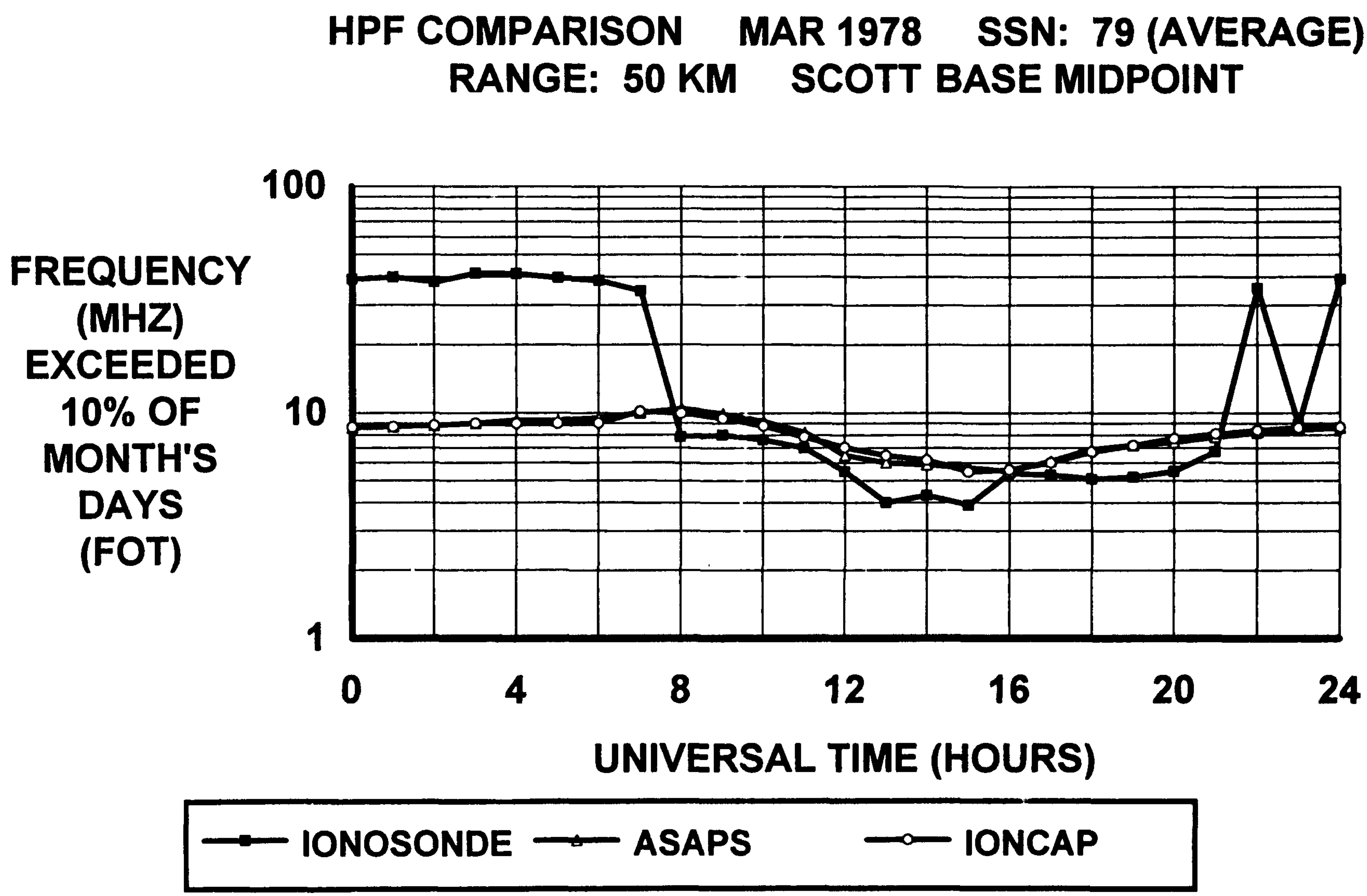


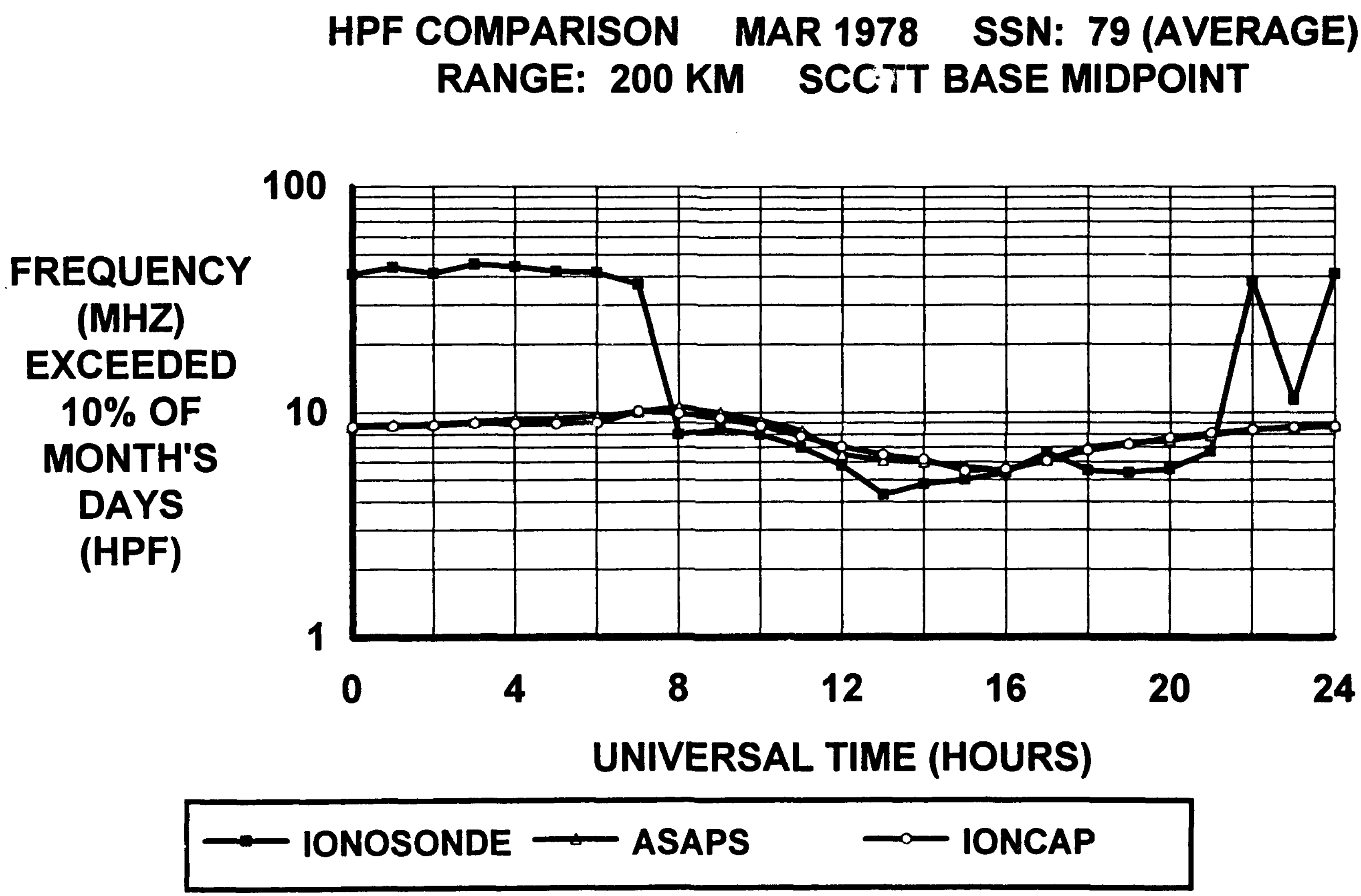

MUF COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


MUF COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

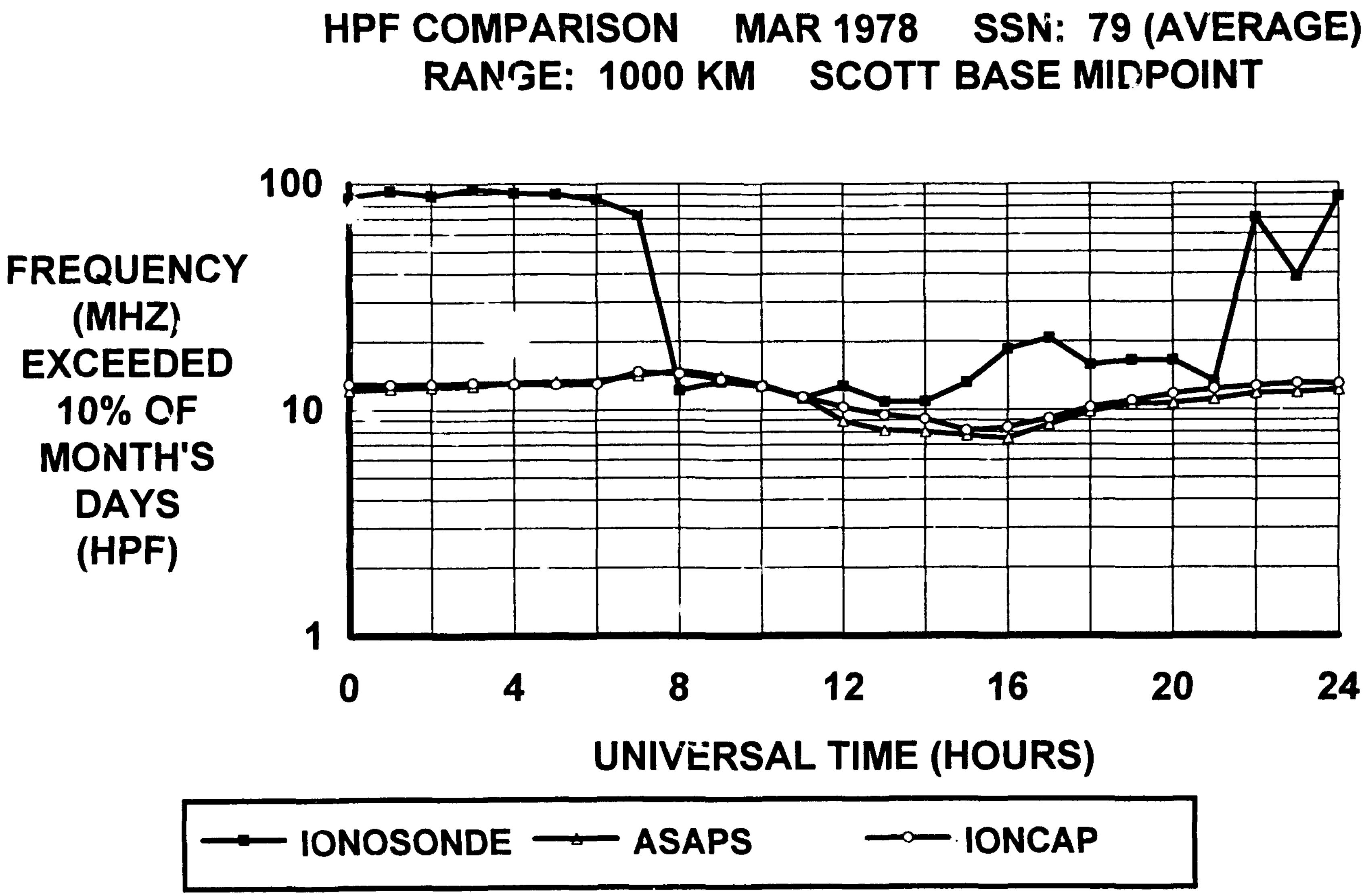
MUF COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT



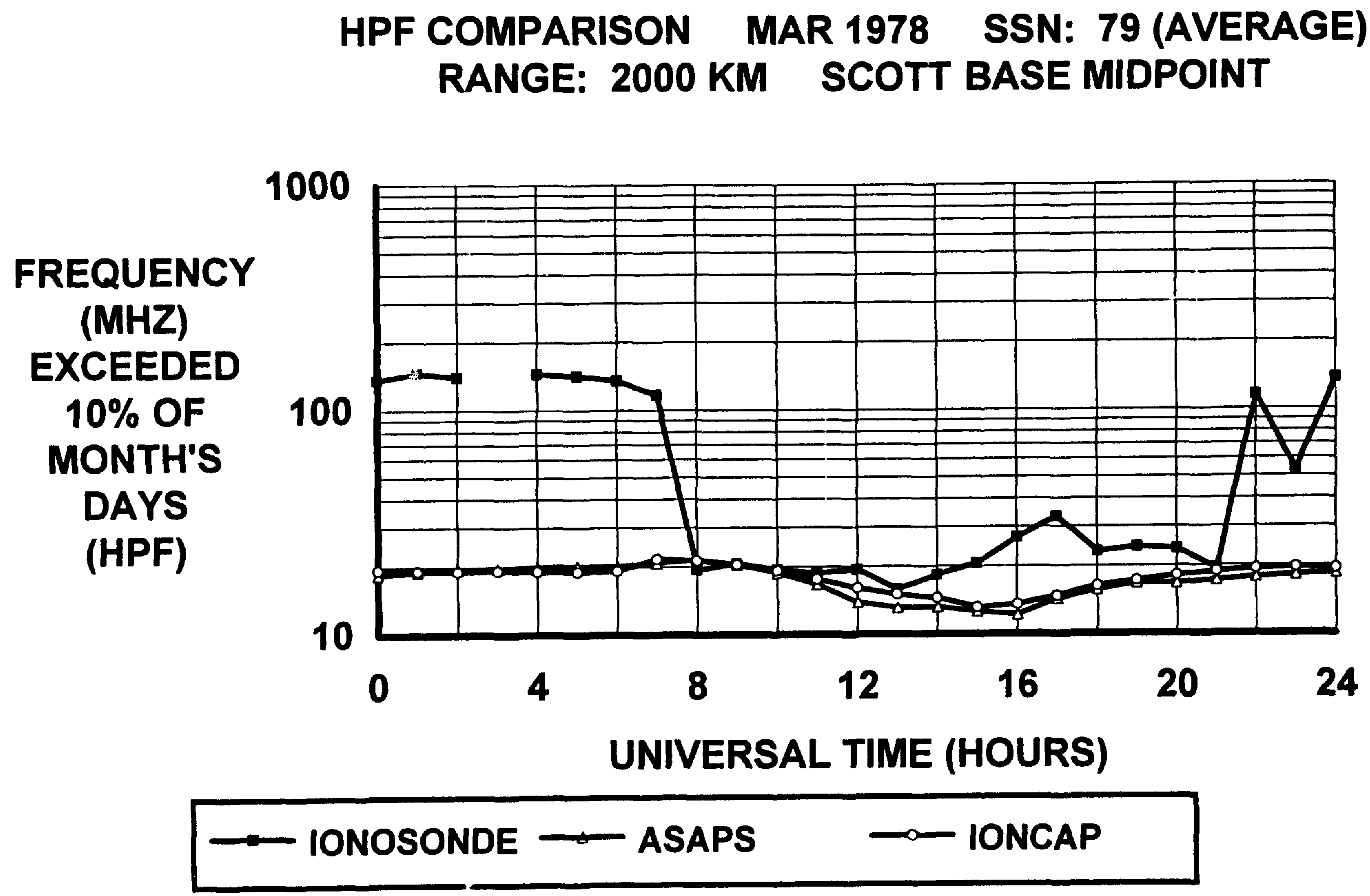

HPF COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


HPF COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

a.



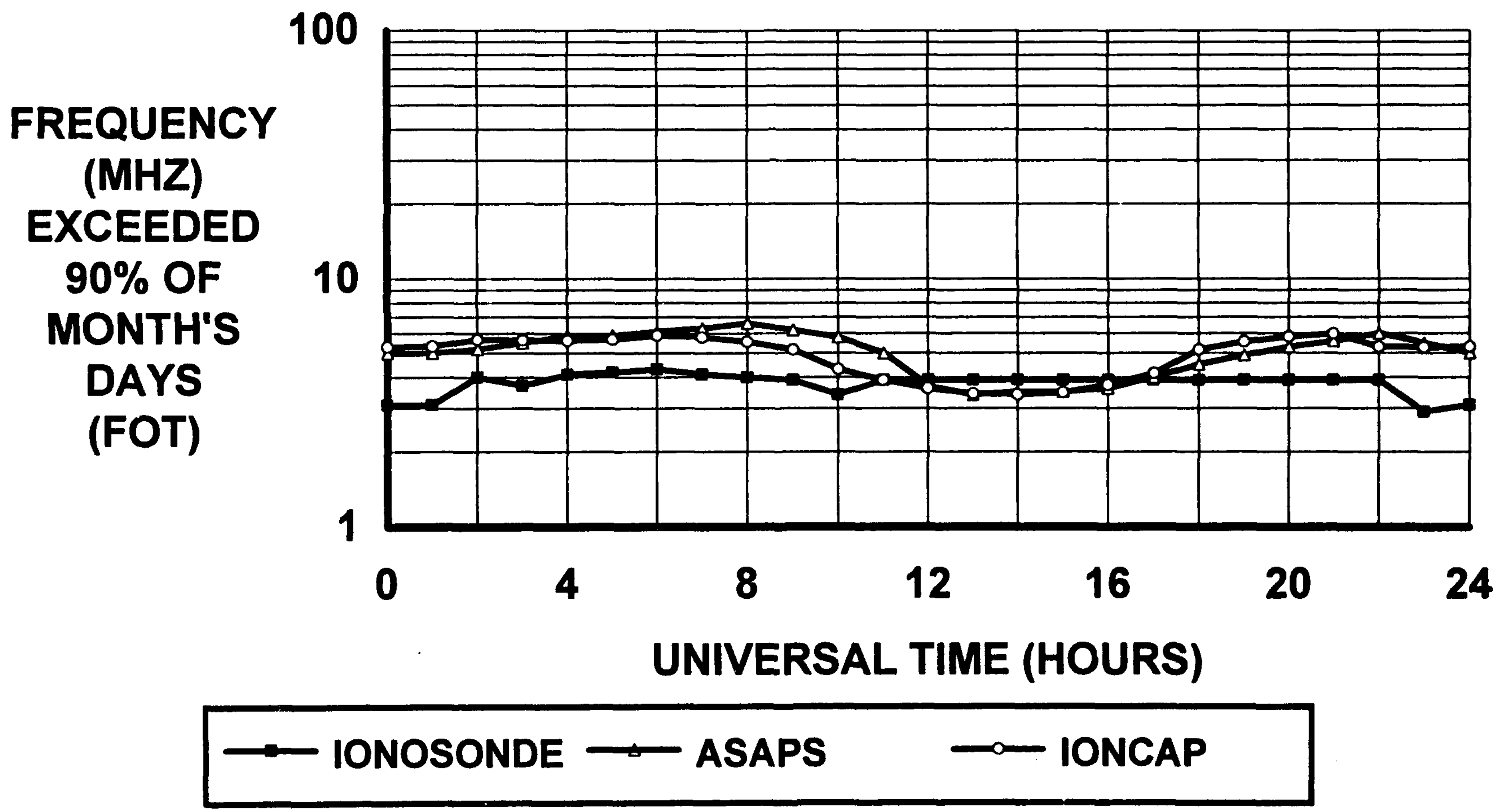
HPF COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 1000 KM SCOTT BASE MIDPOINT
100
10
1
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP



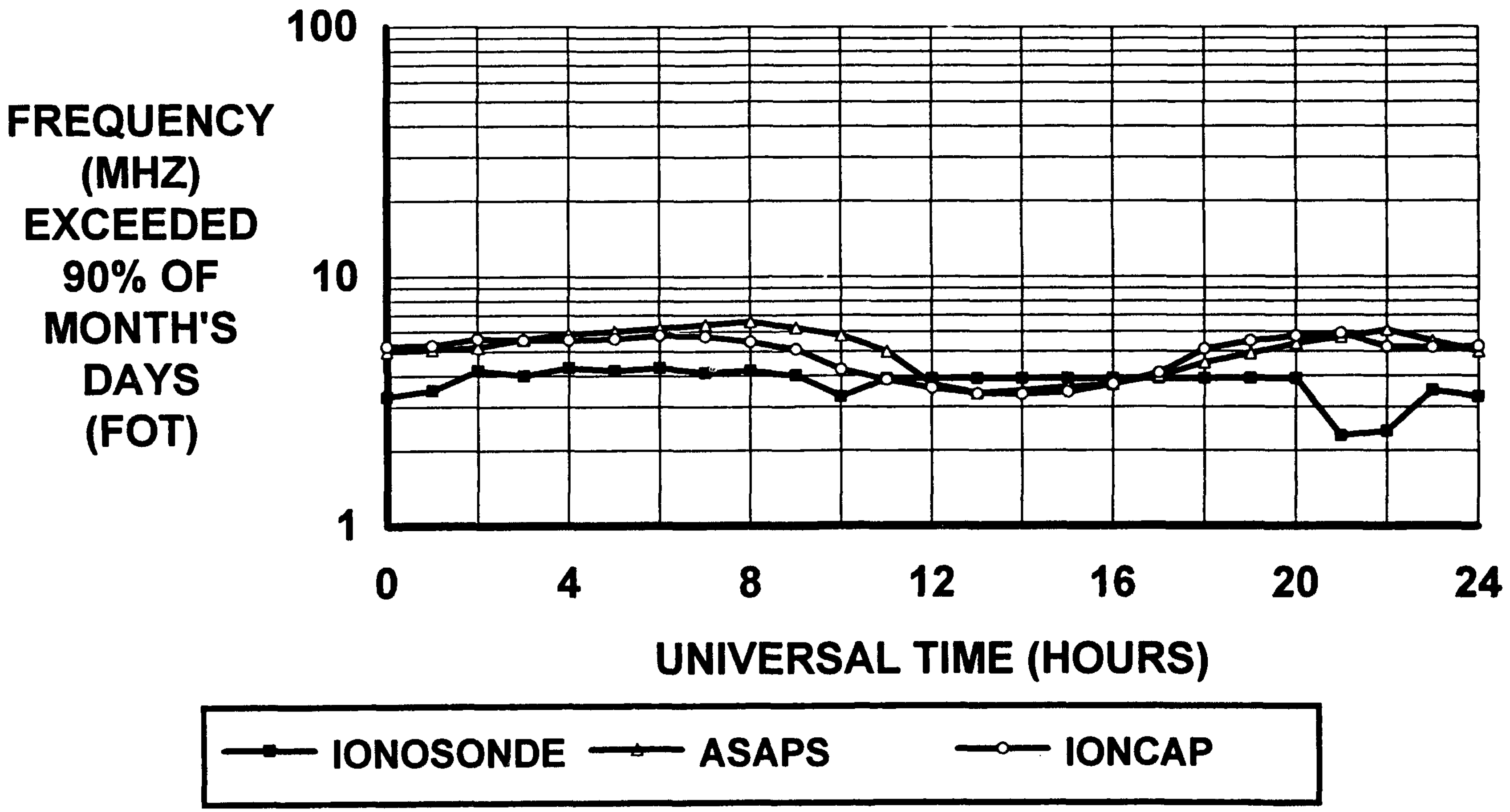
HPF COMPARISON MAR 1978 SSN: 79 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
1000
100
10
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

	DIST PROB VALUE	MARCH SSN / YEAR	MARCH PAGE # to PAGE #	JUNE SSN / YEAR	JUNE PAGE # to PAGE #	SEPTEMBER SSN / YEAR	SEPTEMBER PAGE # to PAGE #	DECEMBER SSN / YEAR	DECEMBER PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

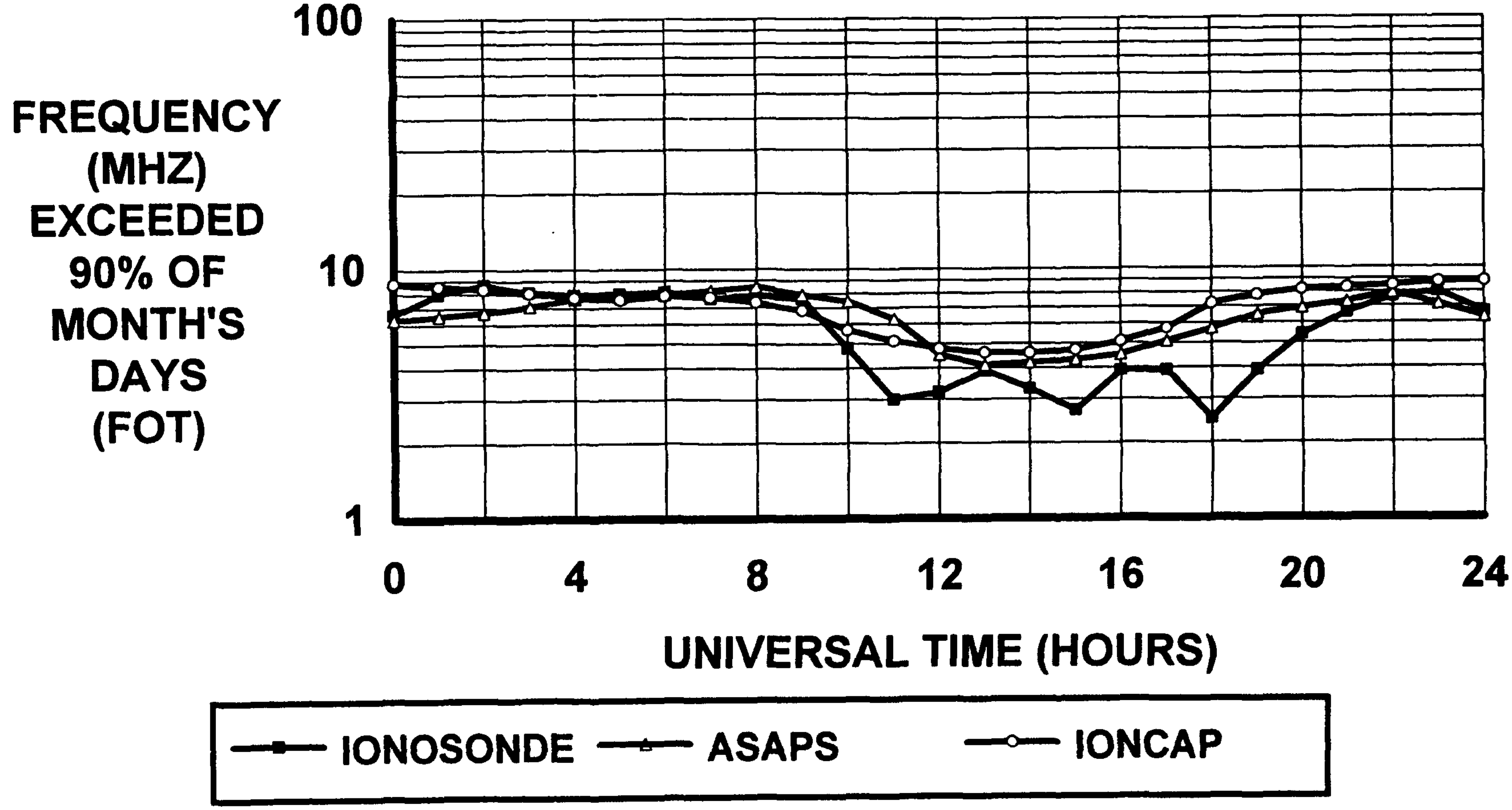
FOT COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT

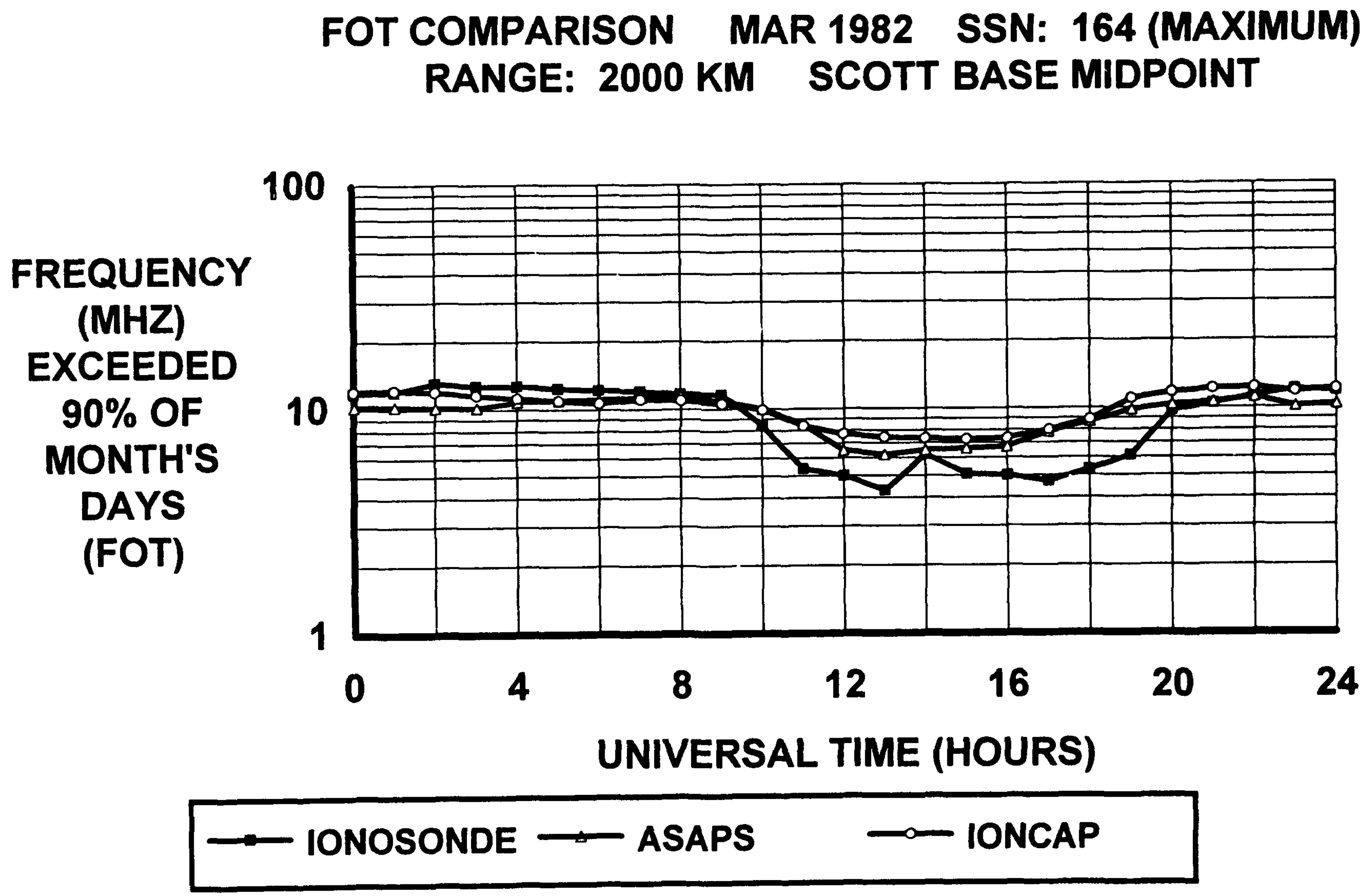


FOT COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT

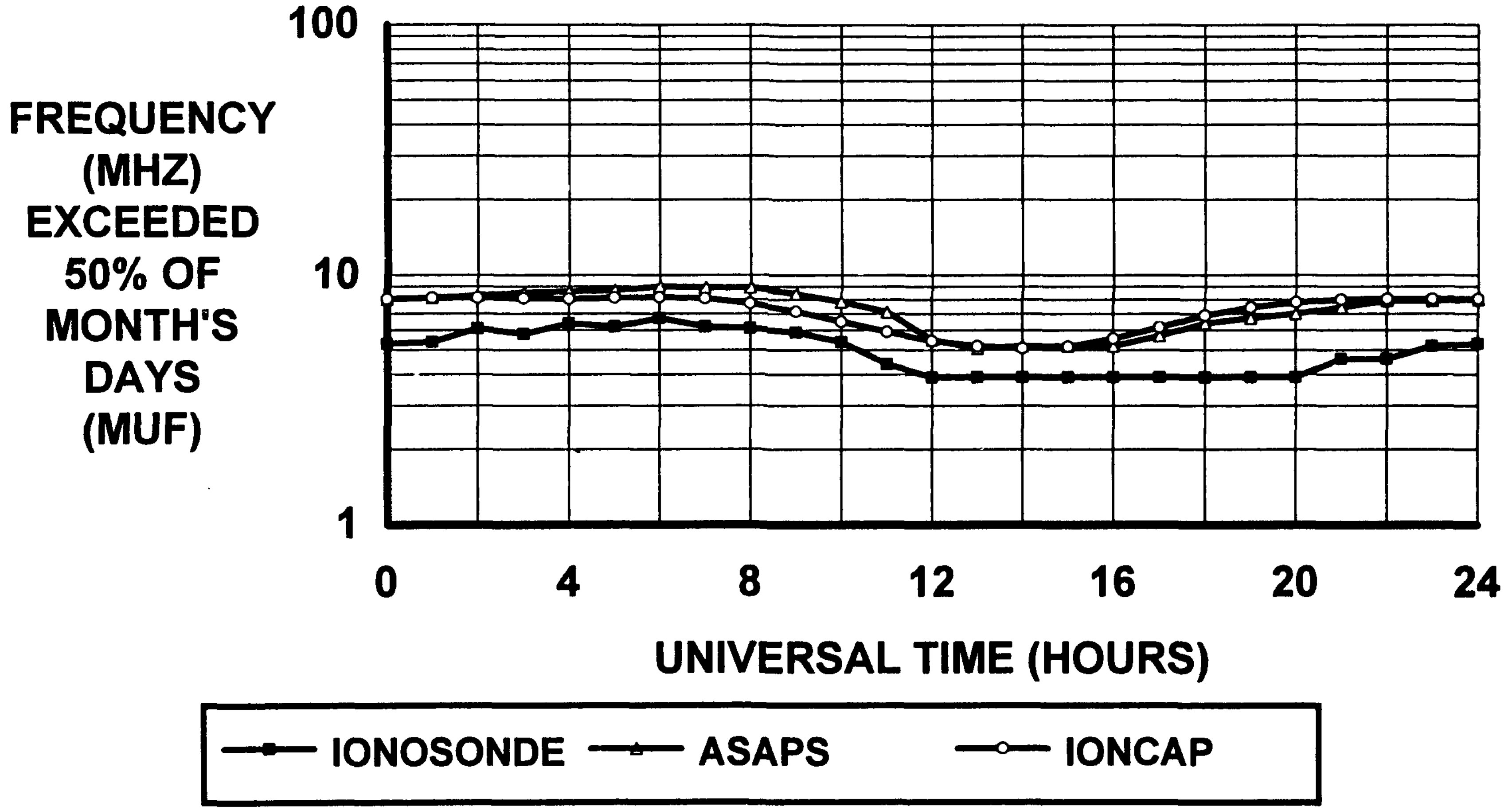


FOT COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT

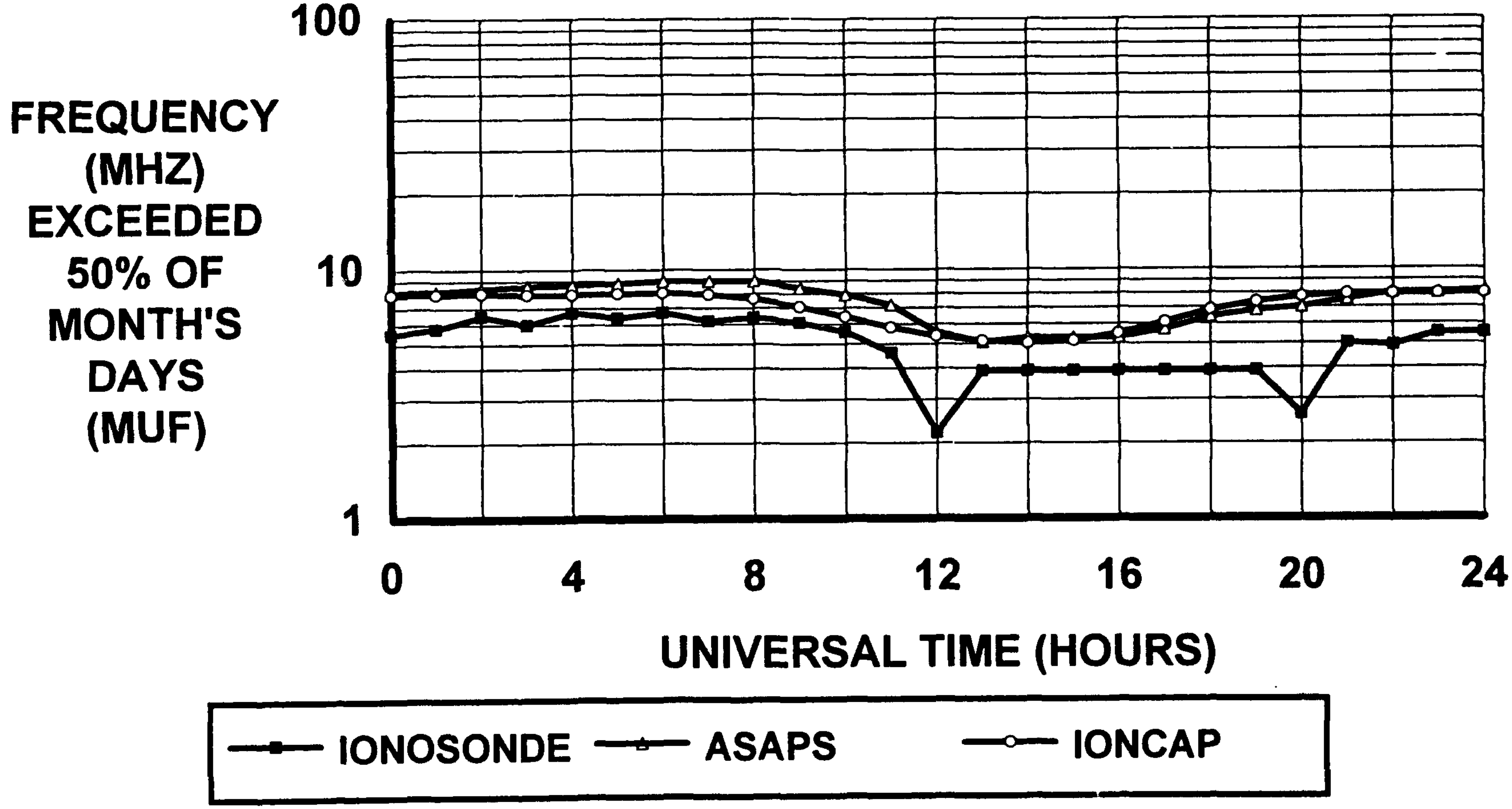



FOT COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

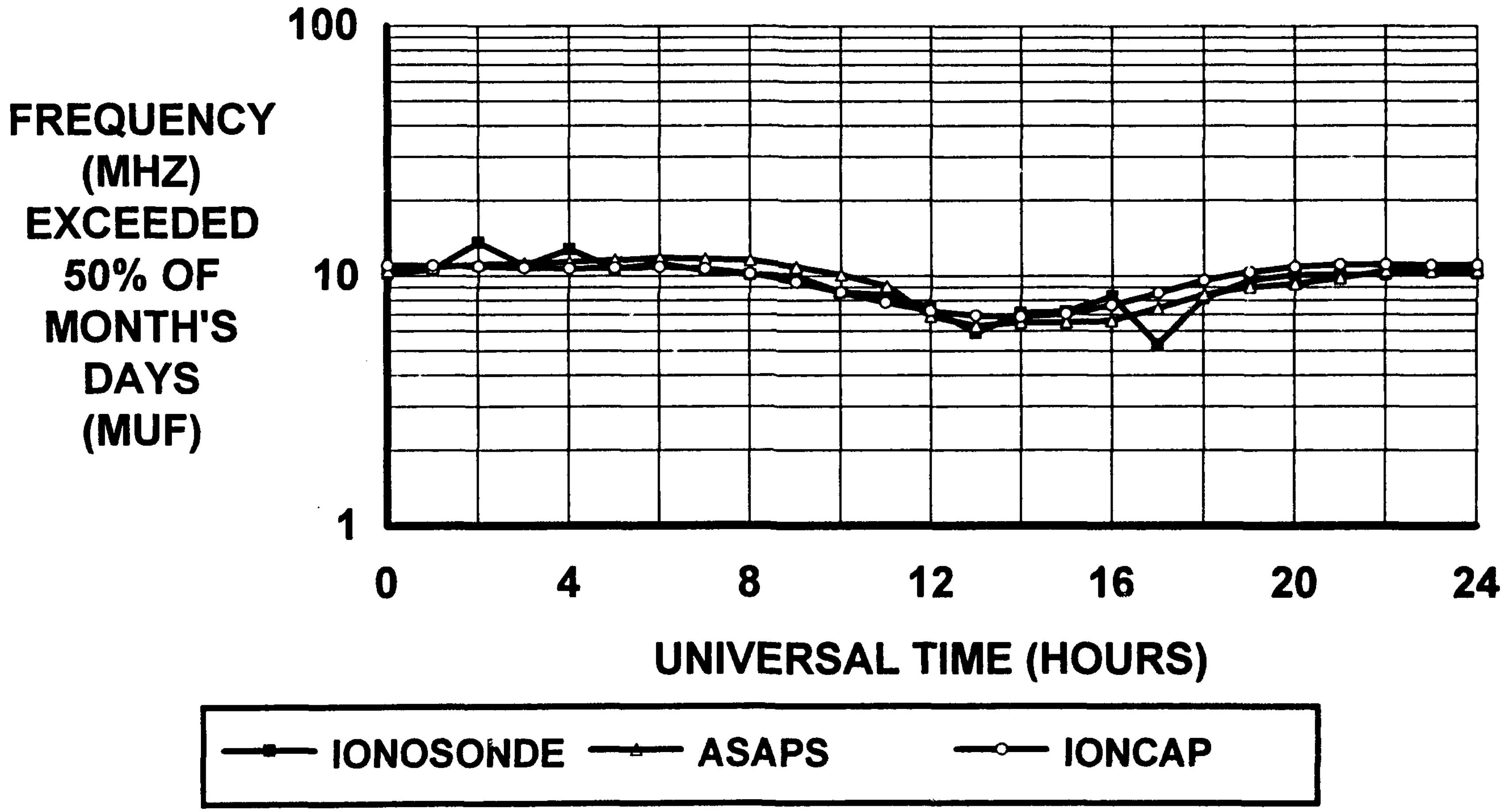
MUF COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT



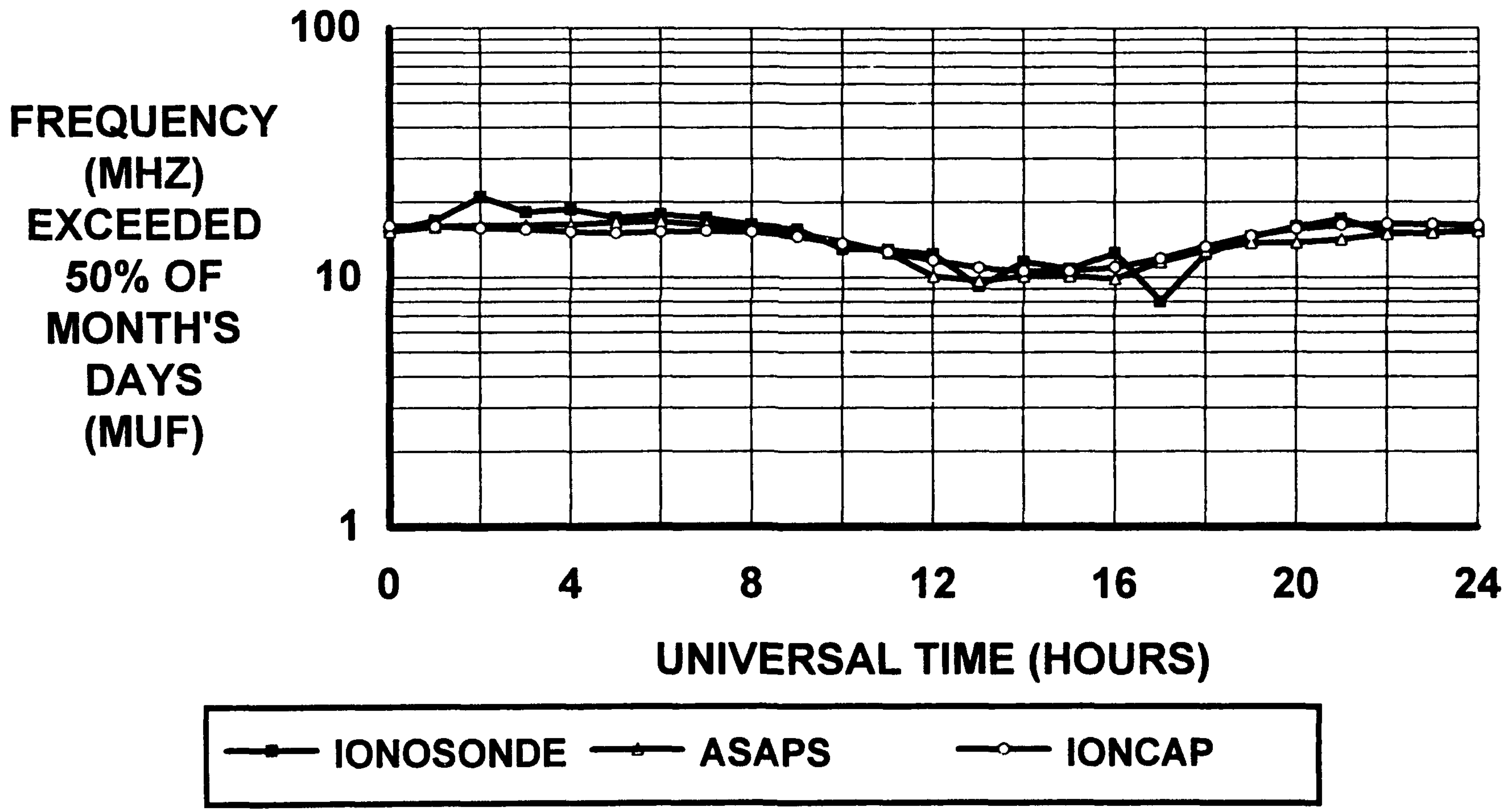
MUF COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT



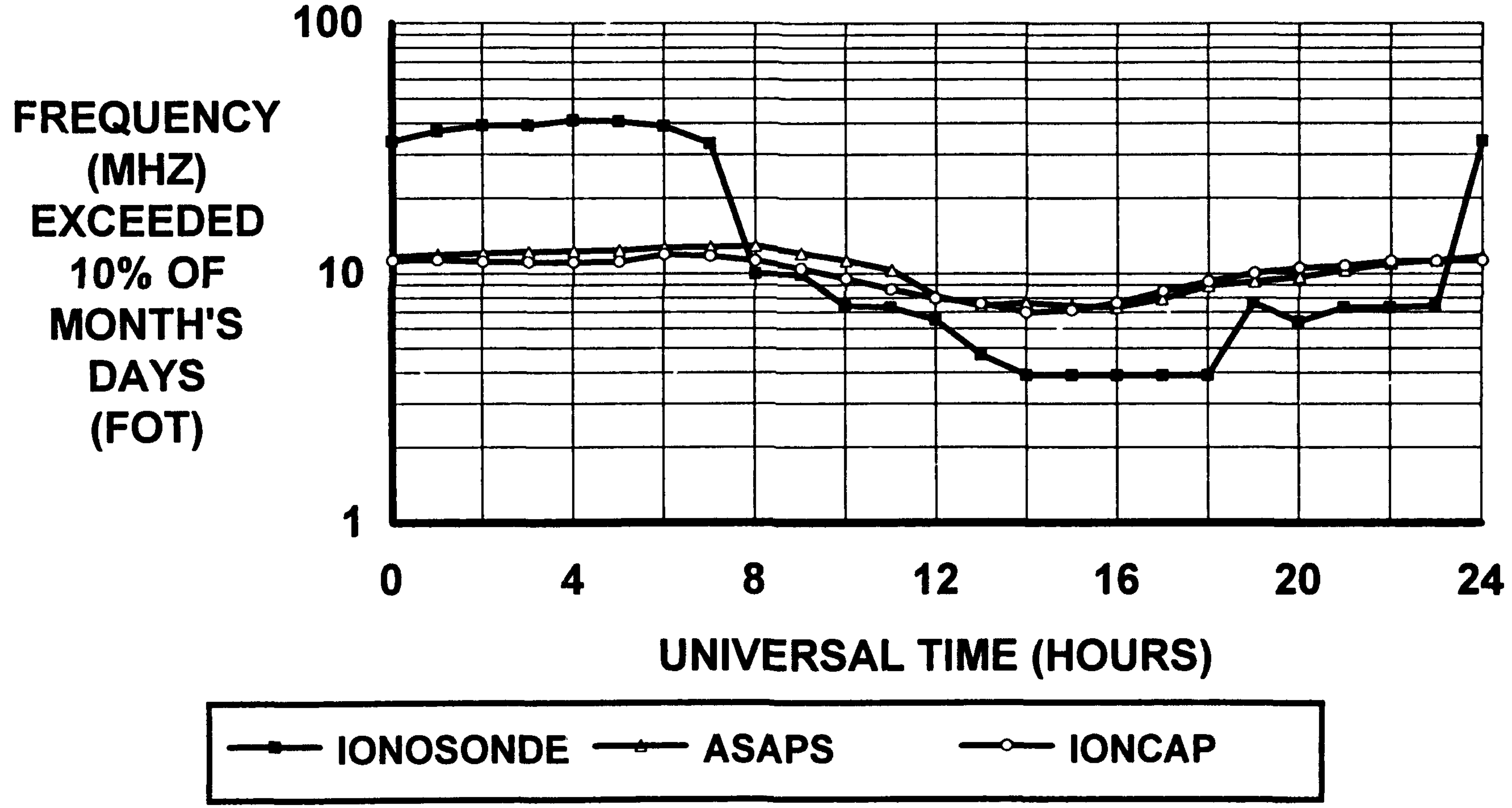
MUF COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT



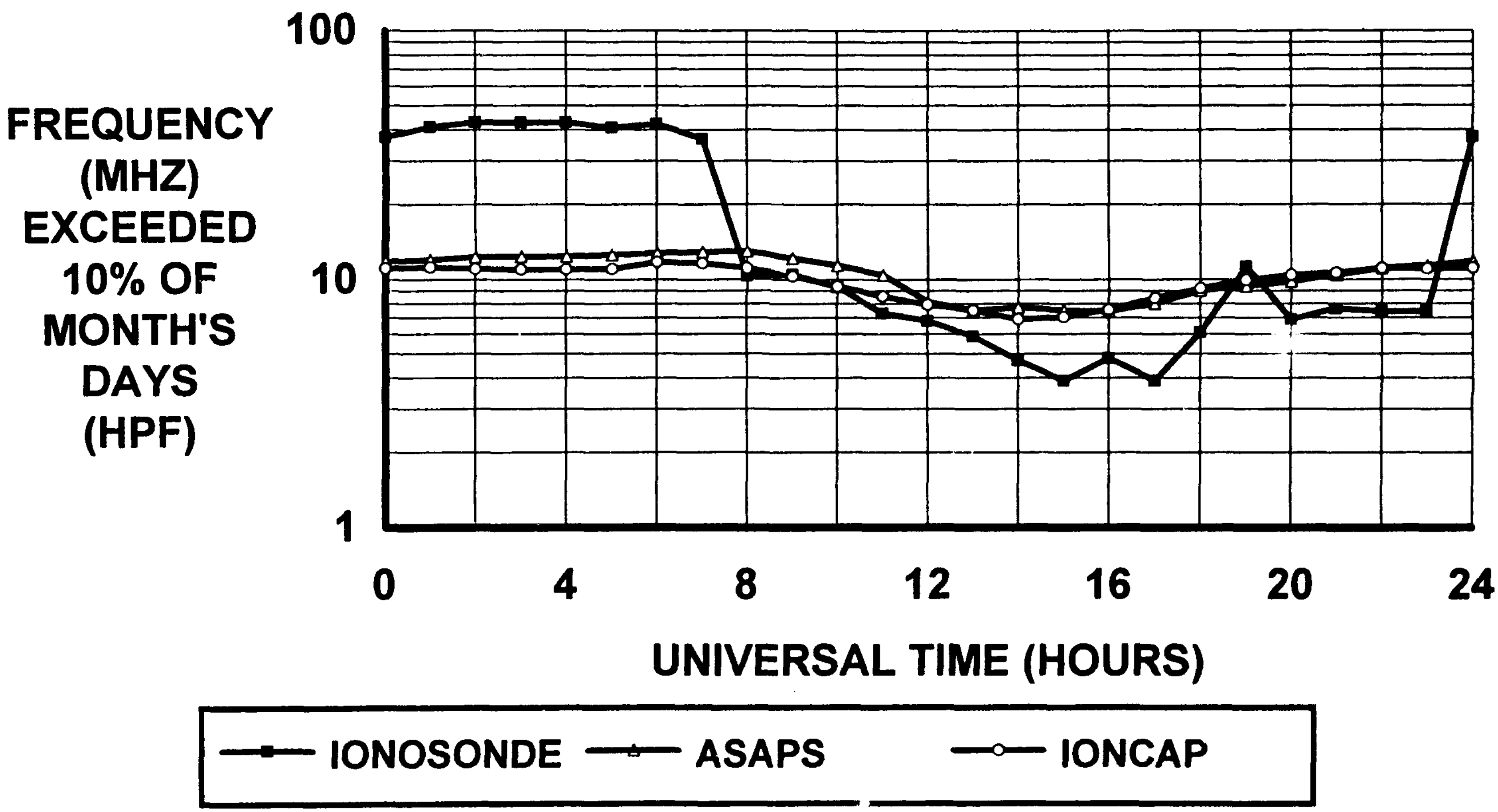
MUF COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT

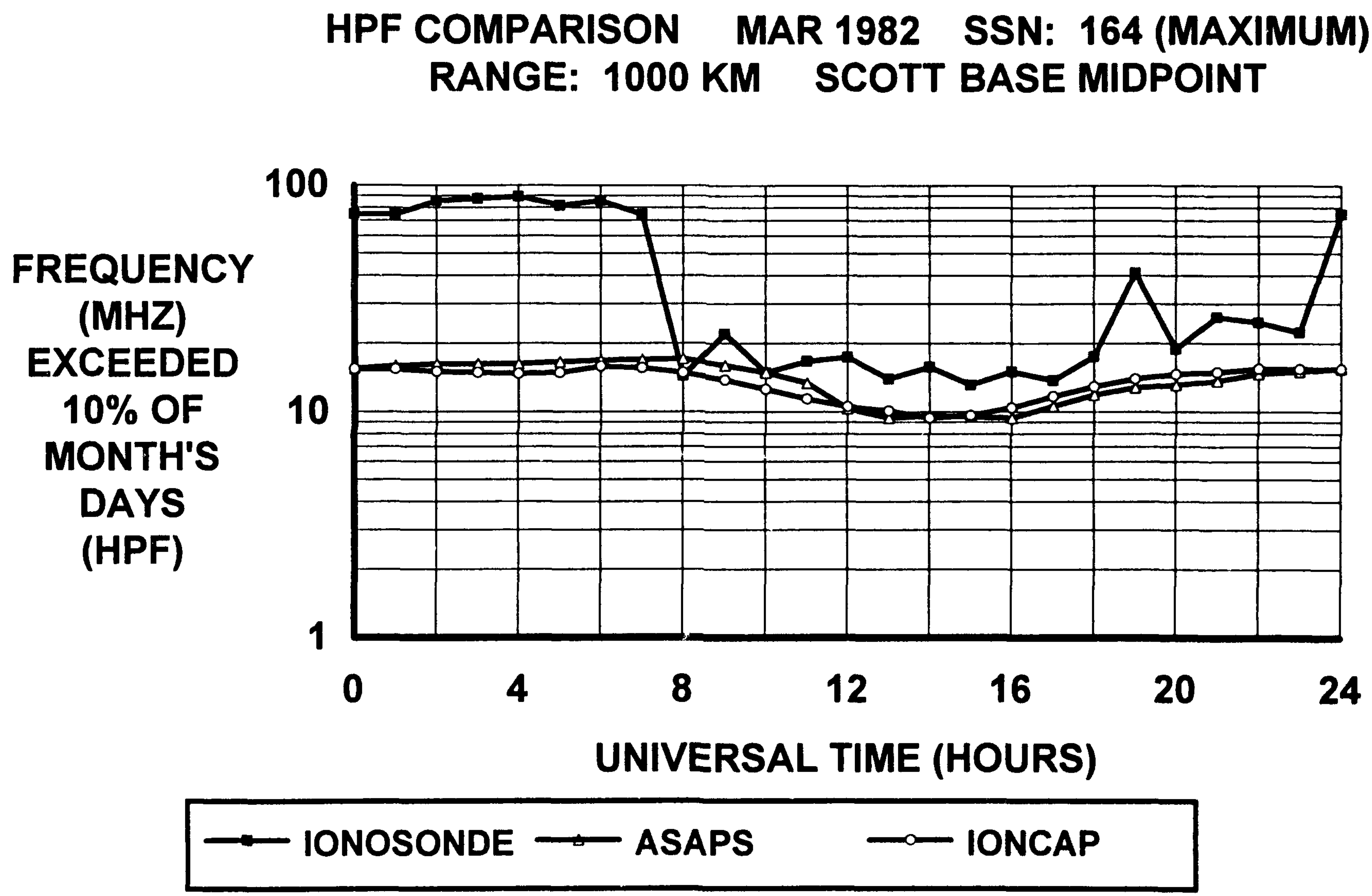


HPF COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT

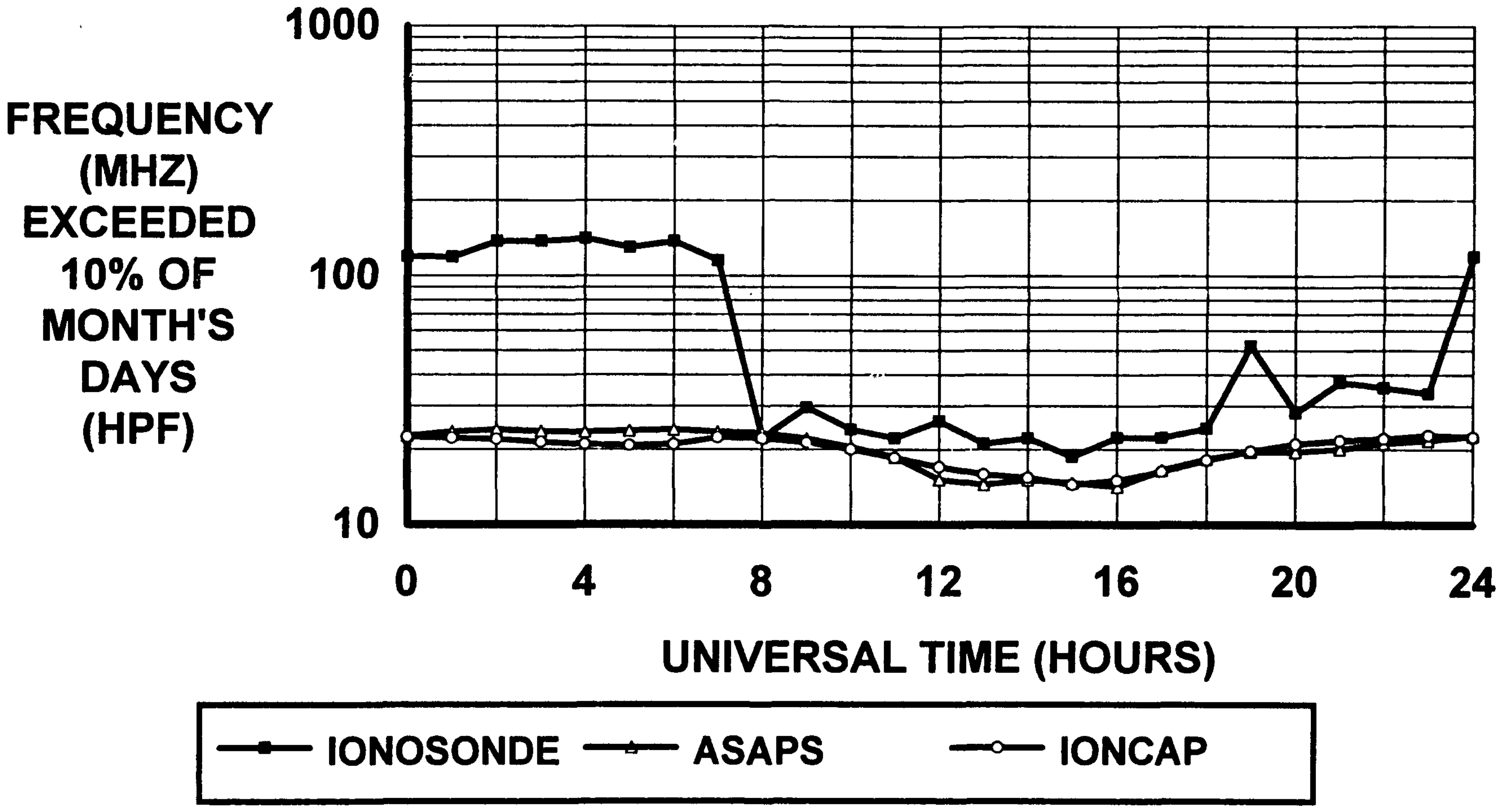


HPF COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT



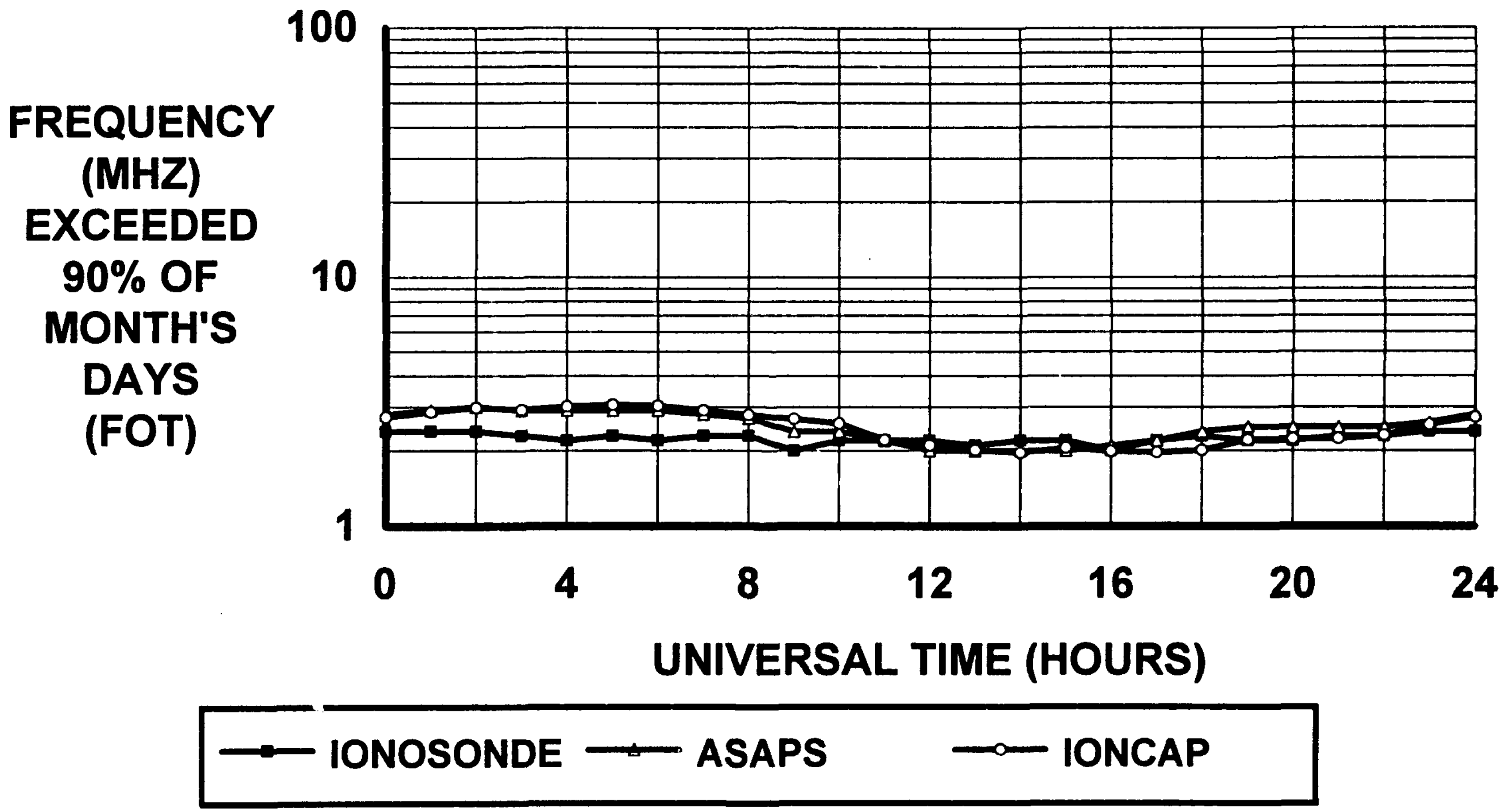

HPF COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

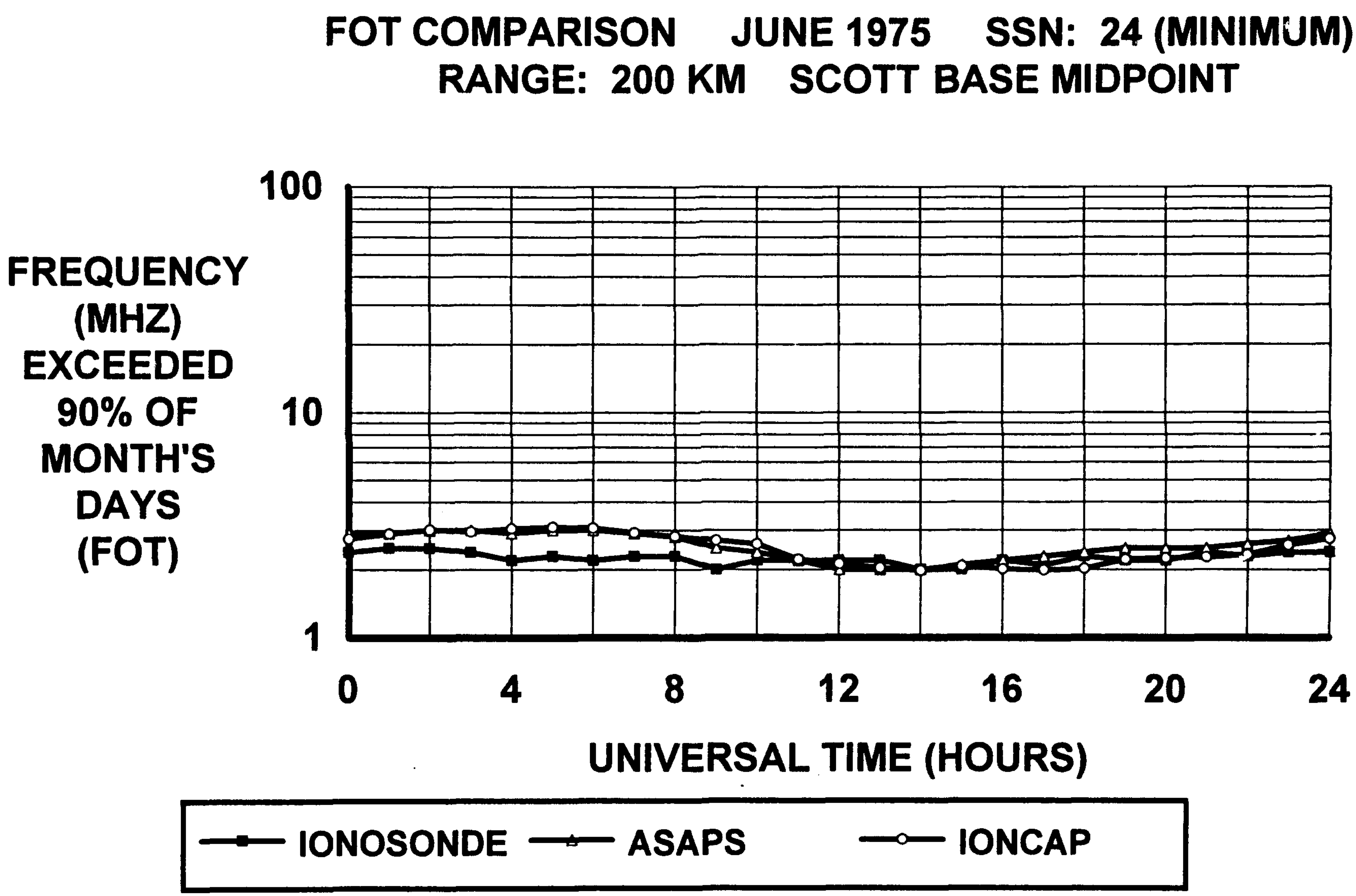
HPF COMPARISON MAR 1982 SSN: 164 (MAXIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT

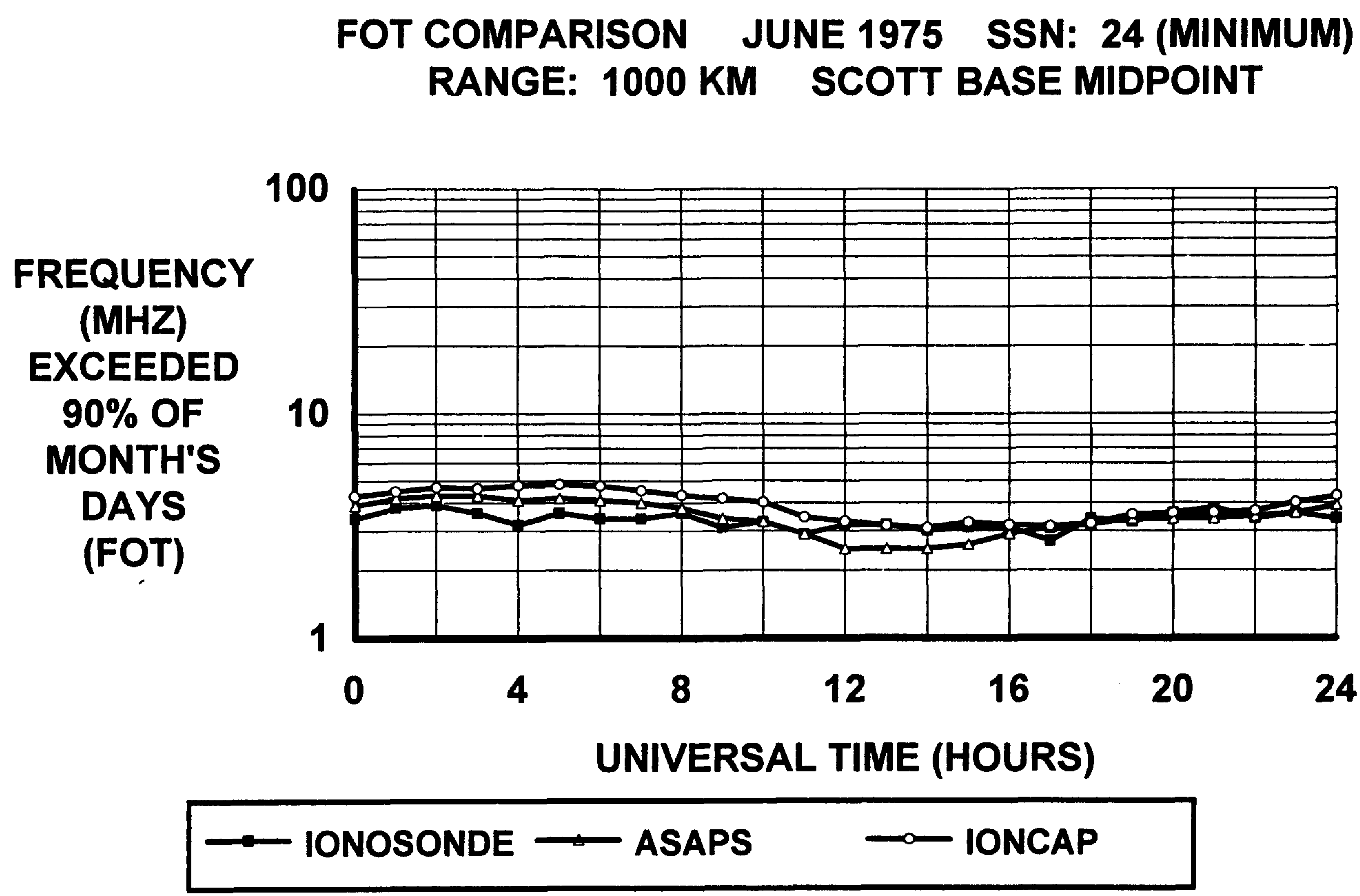


		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

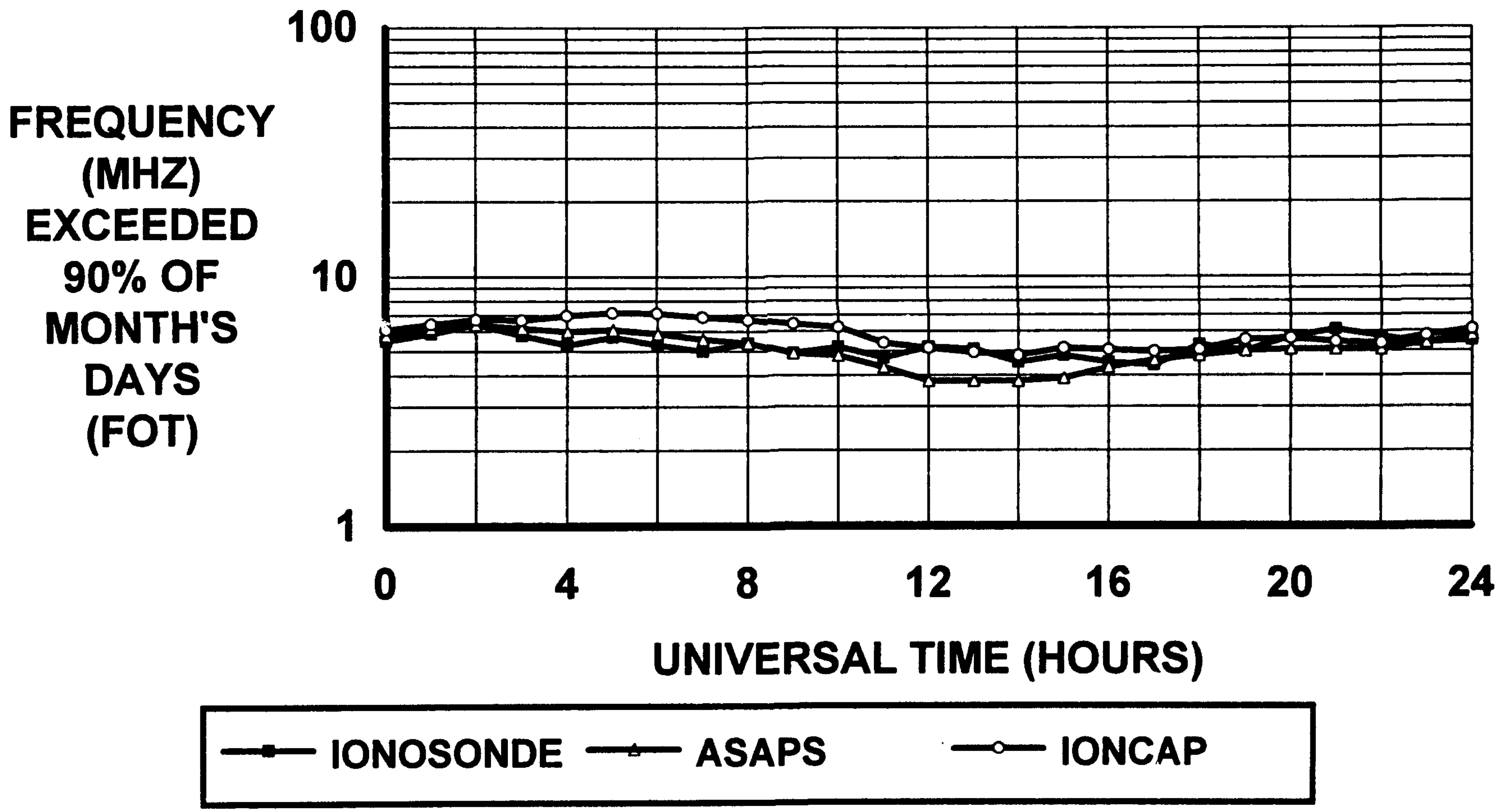
FOT COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT

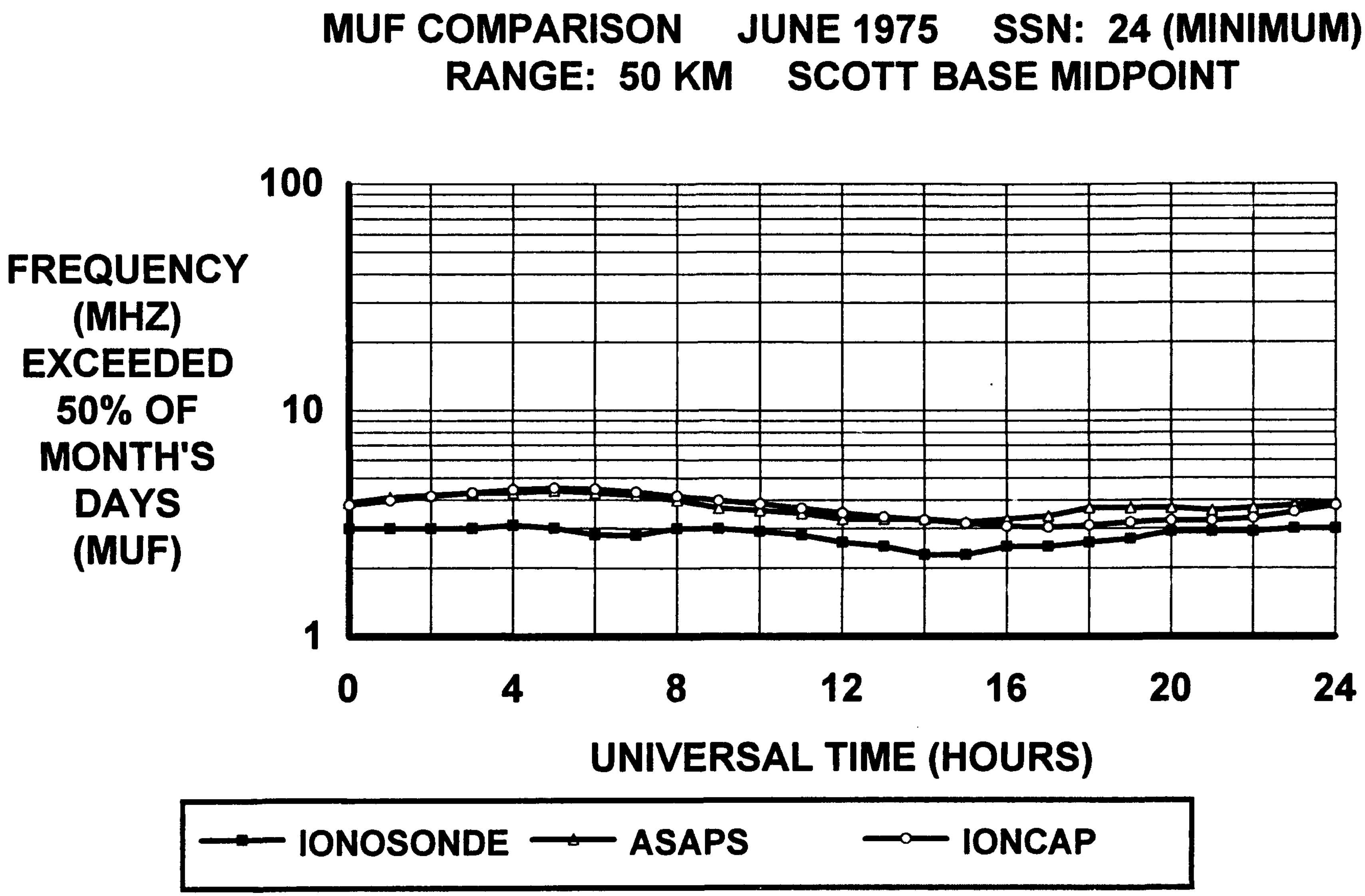


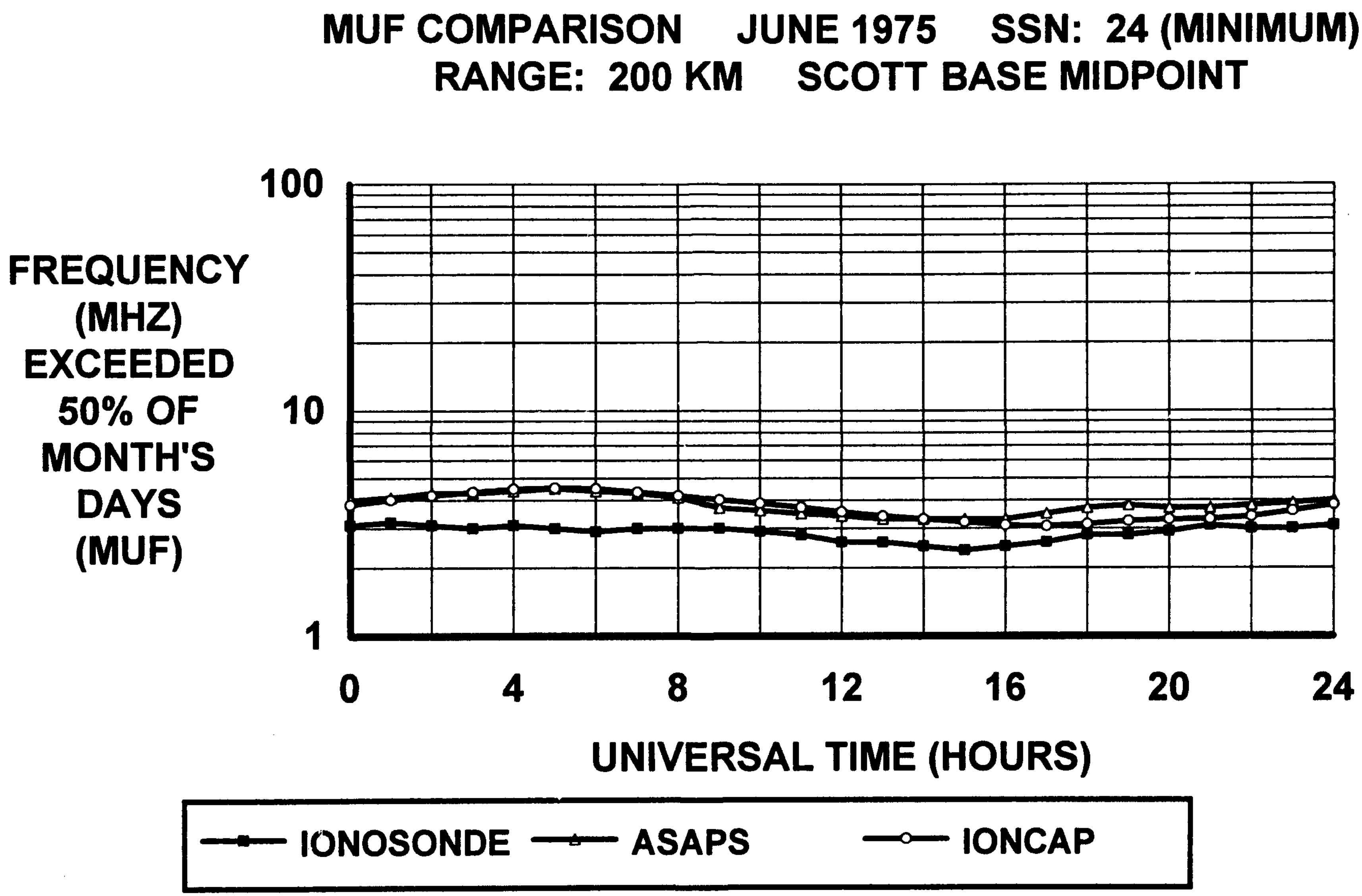

FOT COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


FOT COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

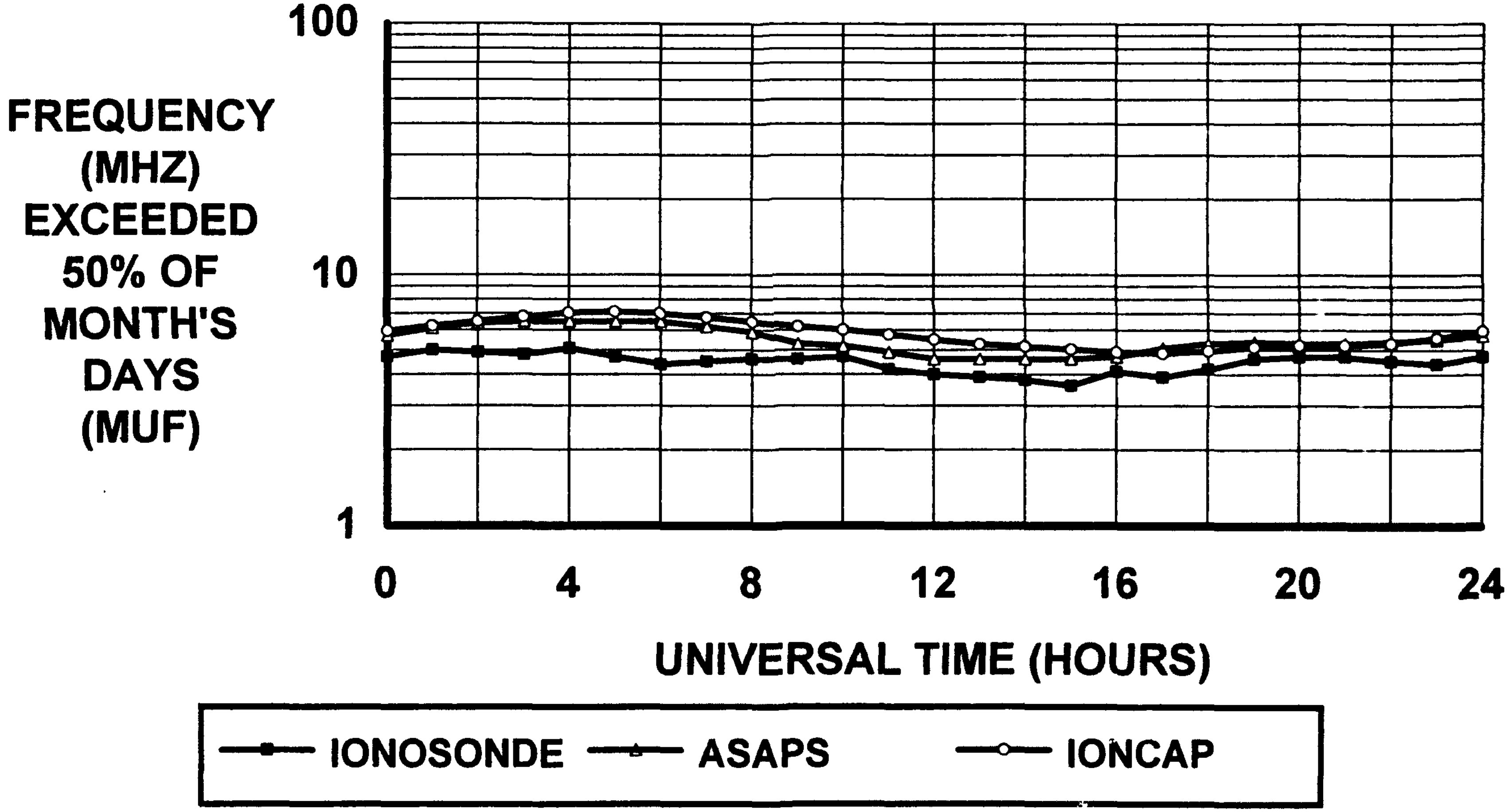
FOT COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT



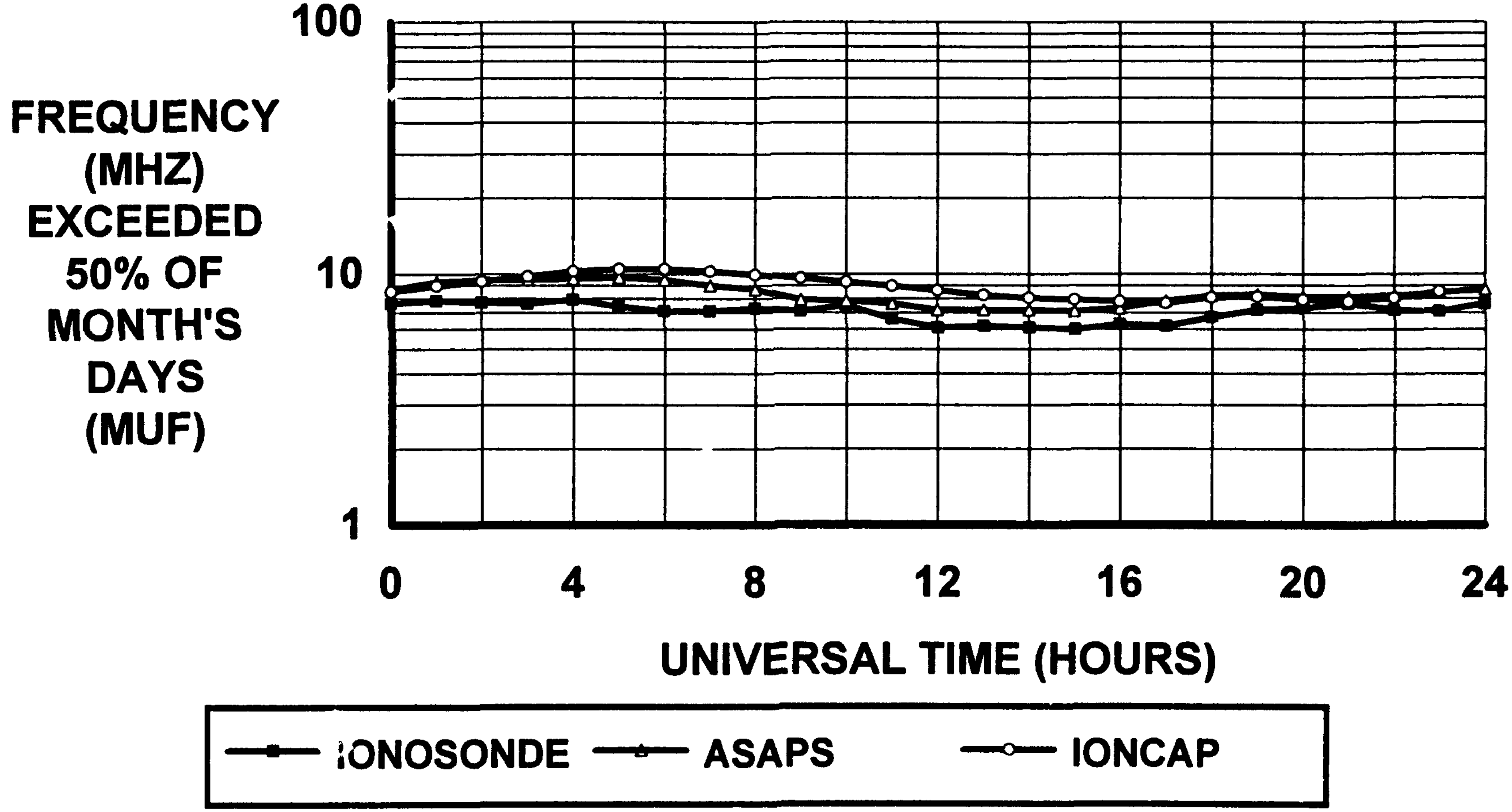

MUF COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

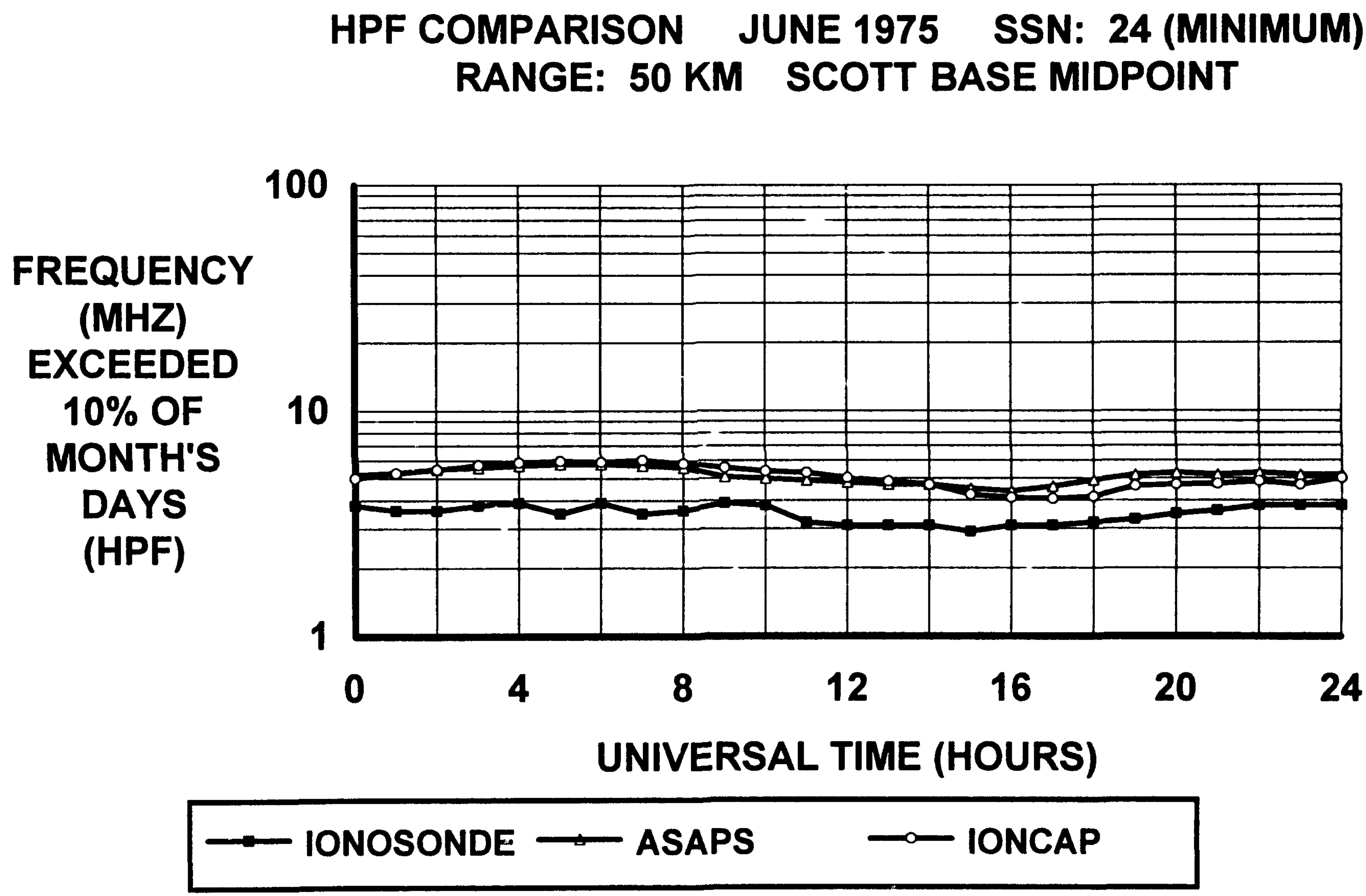

MUF COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

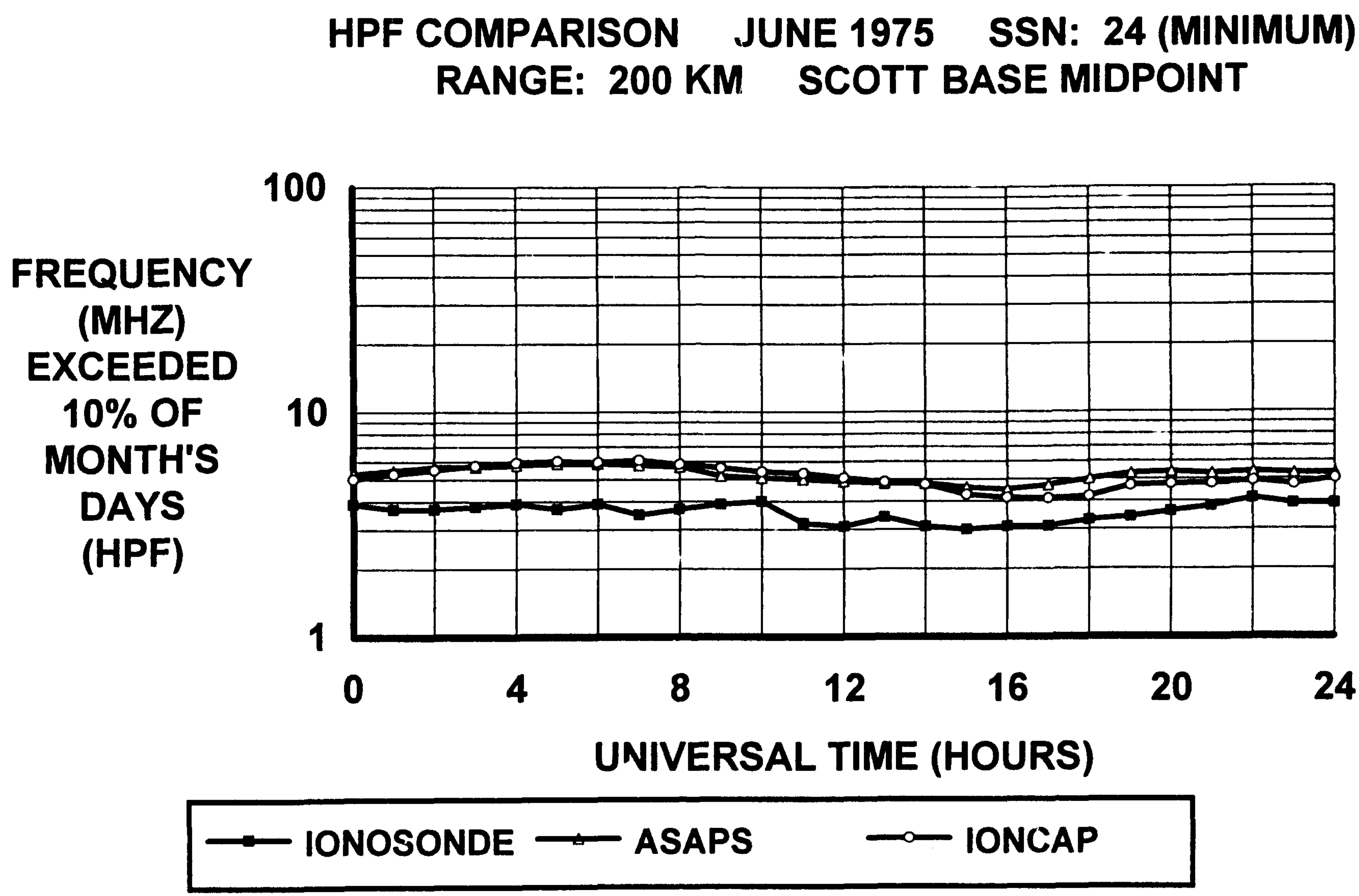
MUF COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT



MUF COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT

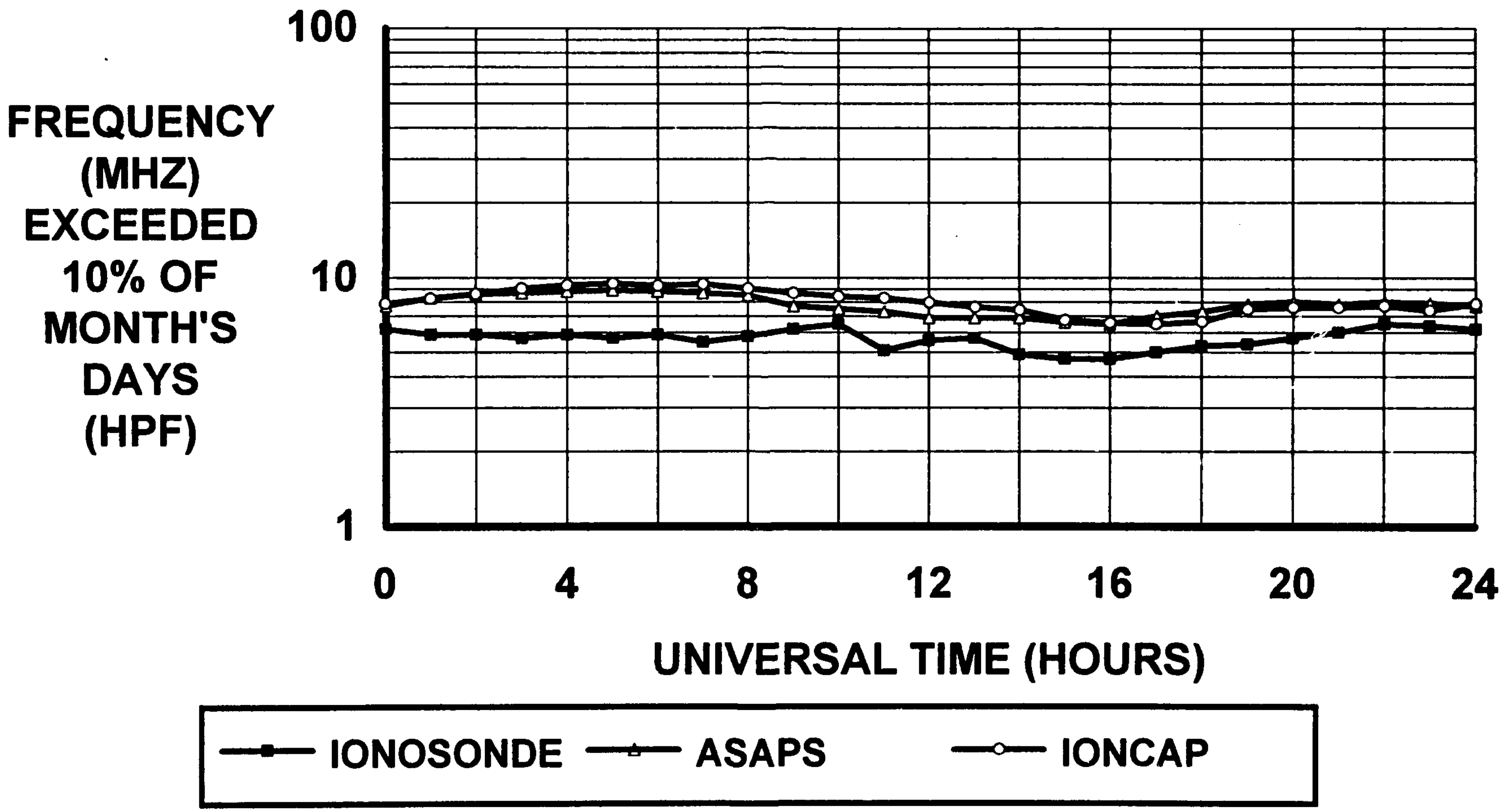


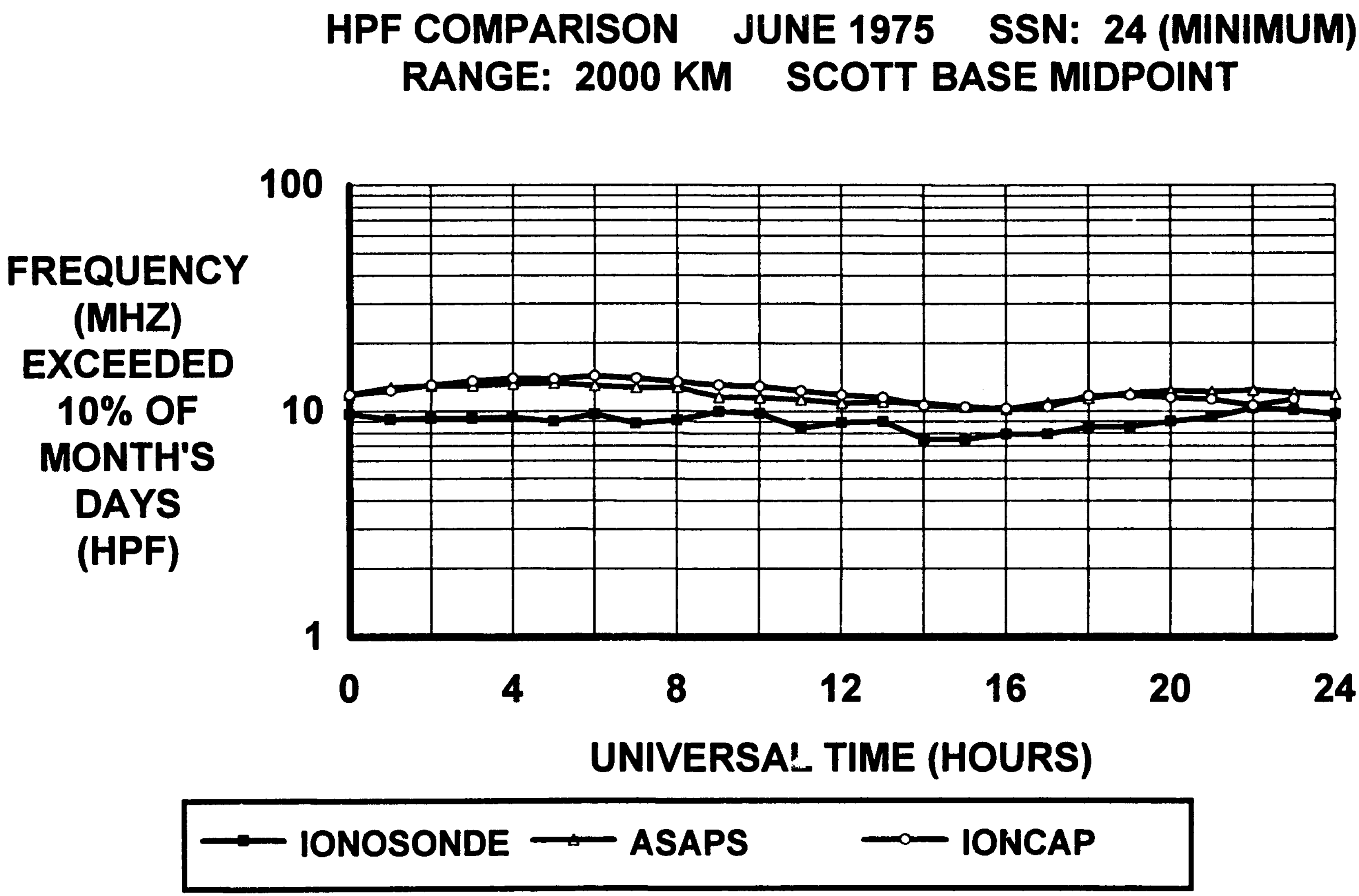

HPF COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP



HPF COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

HPF COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT

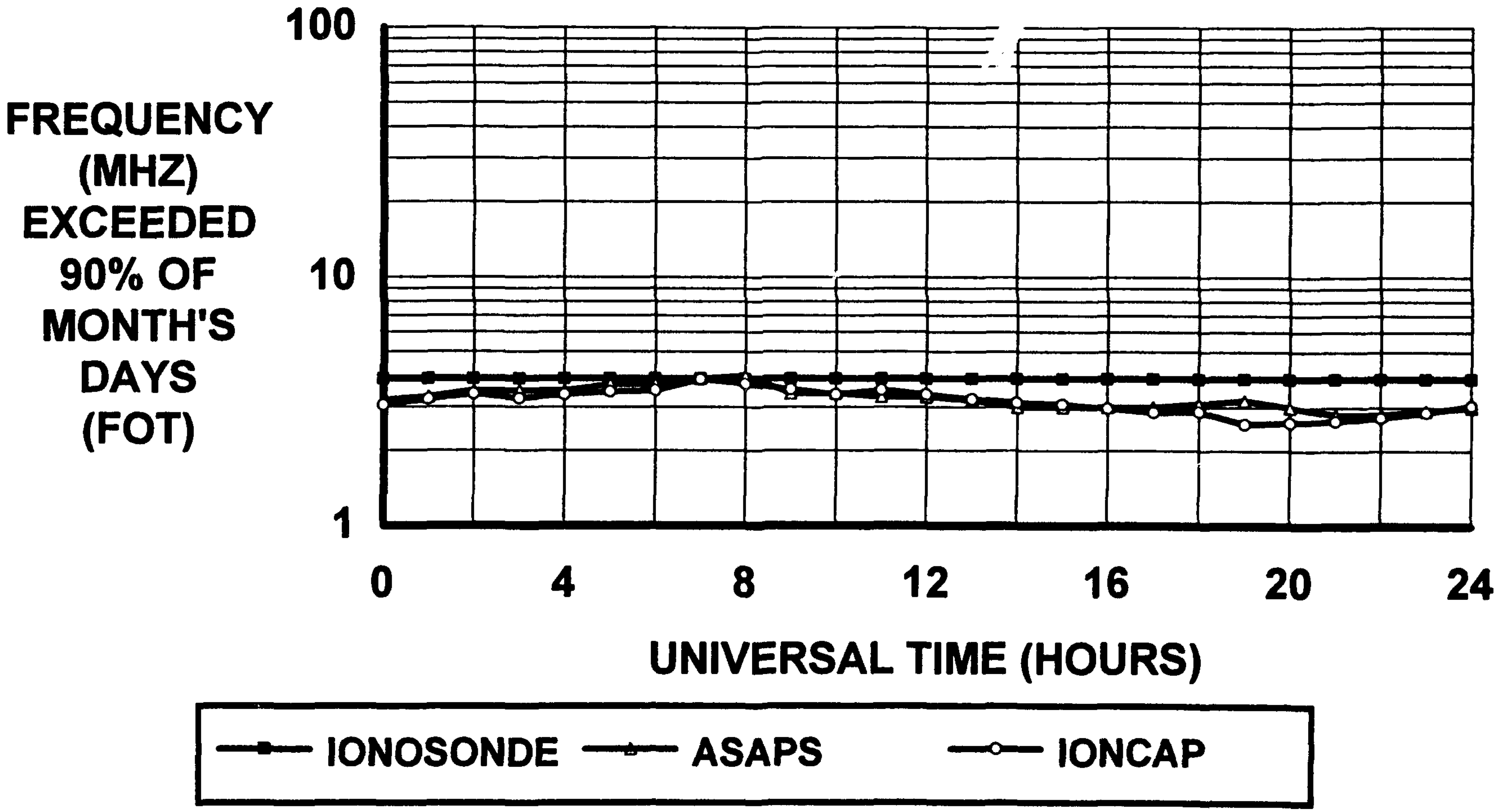




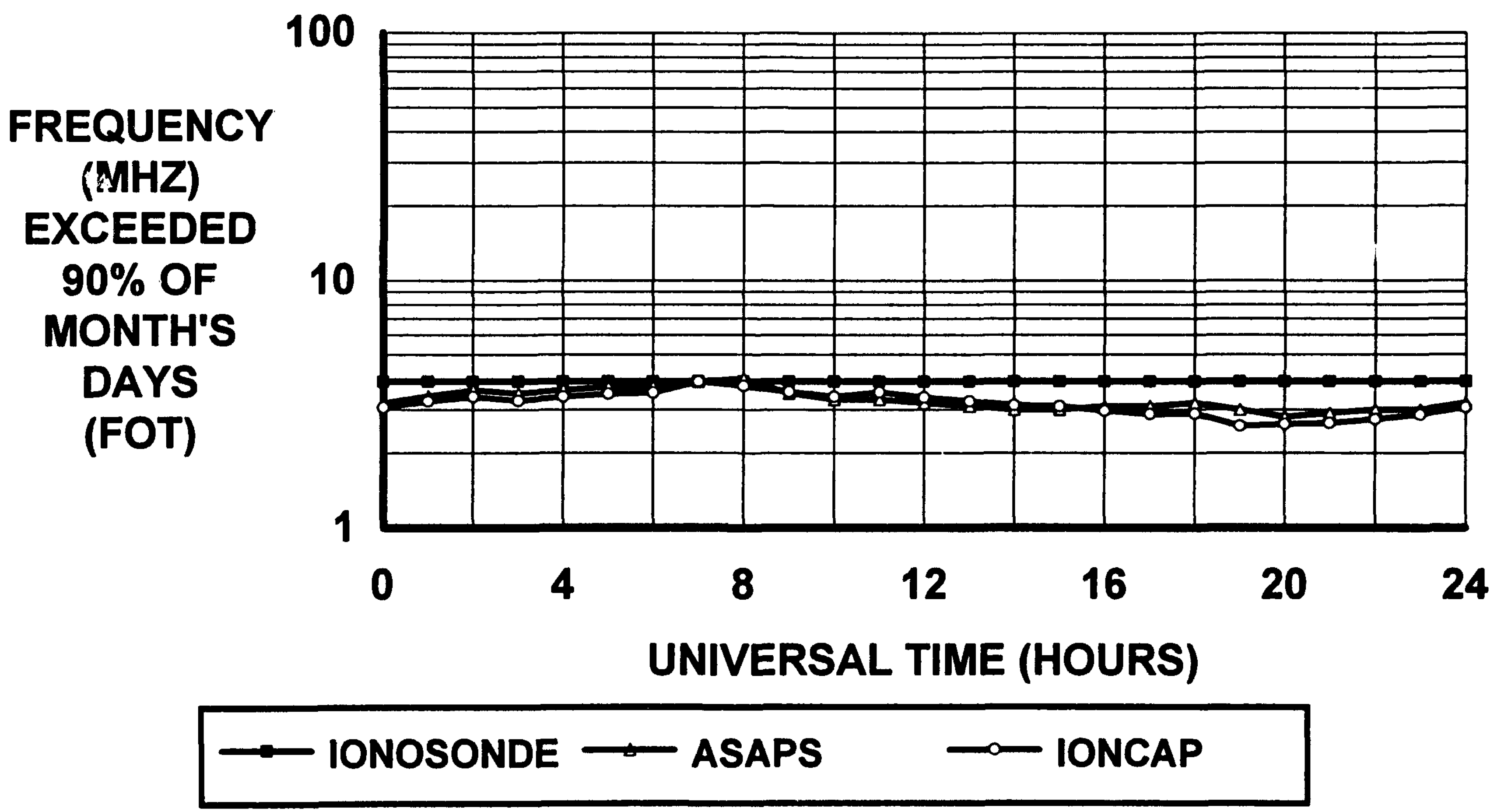
HPF COMPARISON JUNE 1975 SSN: 24 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

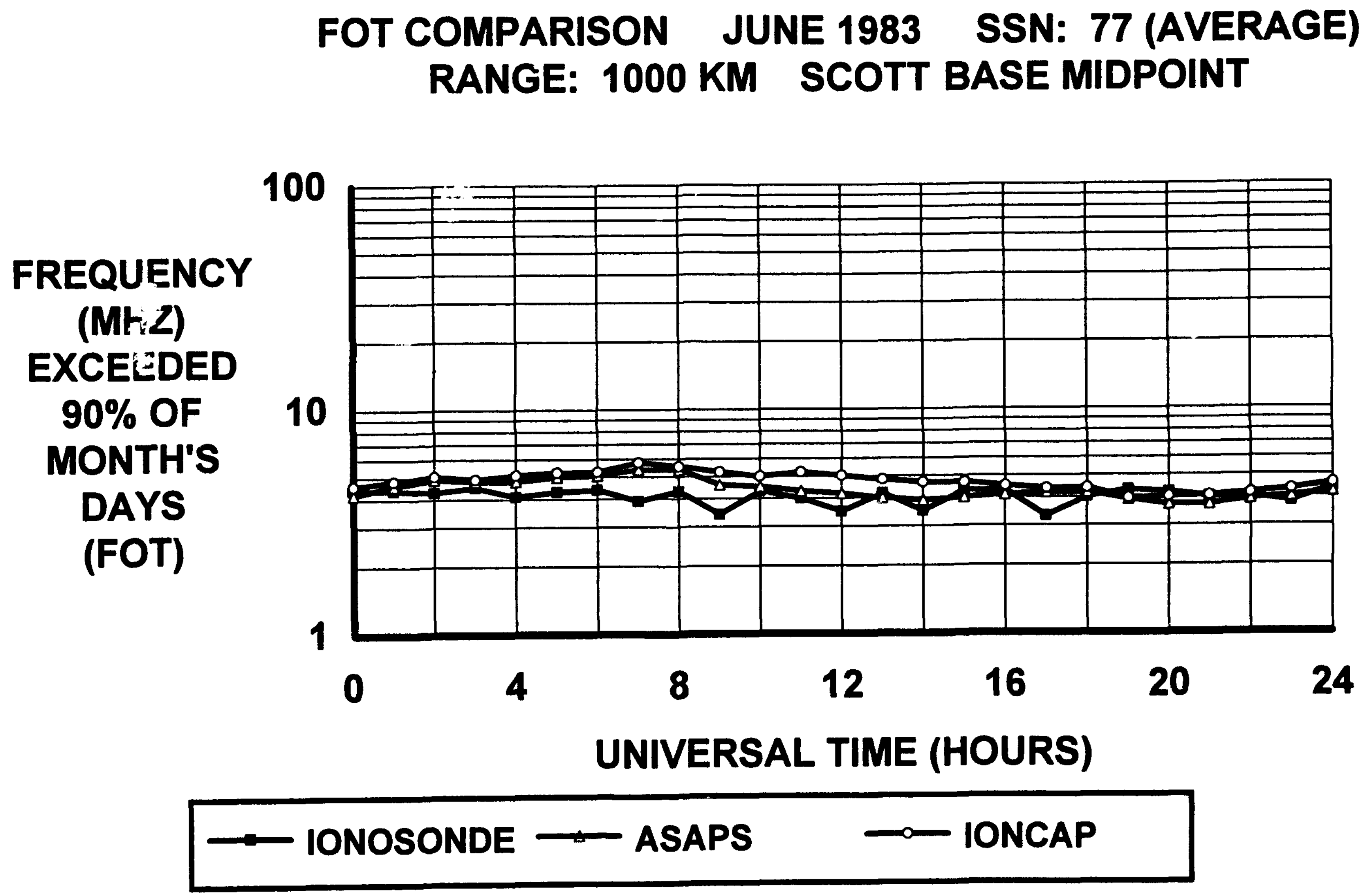
		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

FOT COMPARISON JUNE 1983 SSN: 77 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT

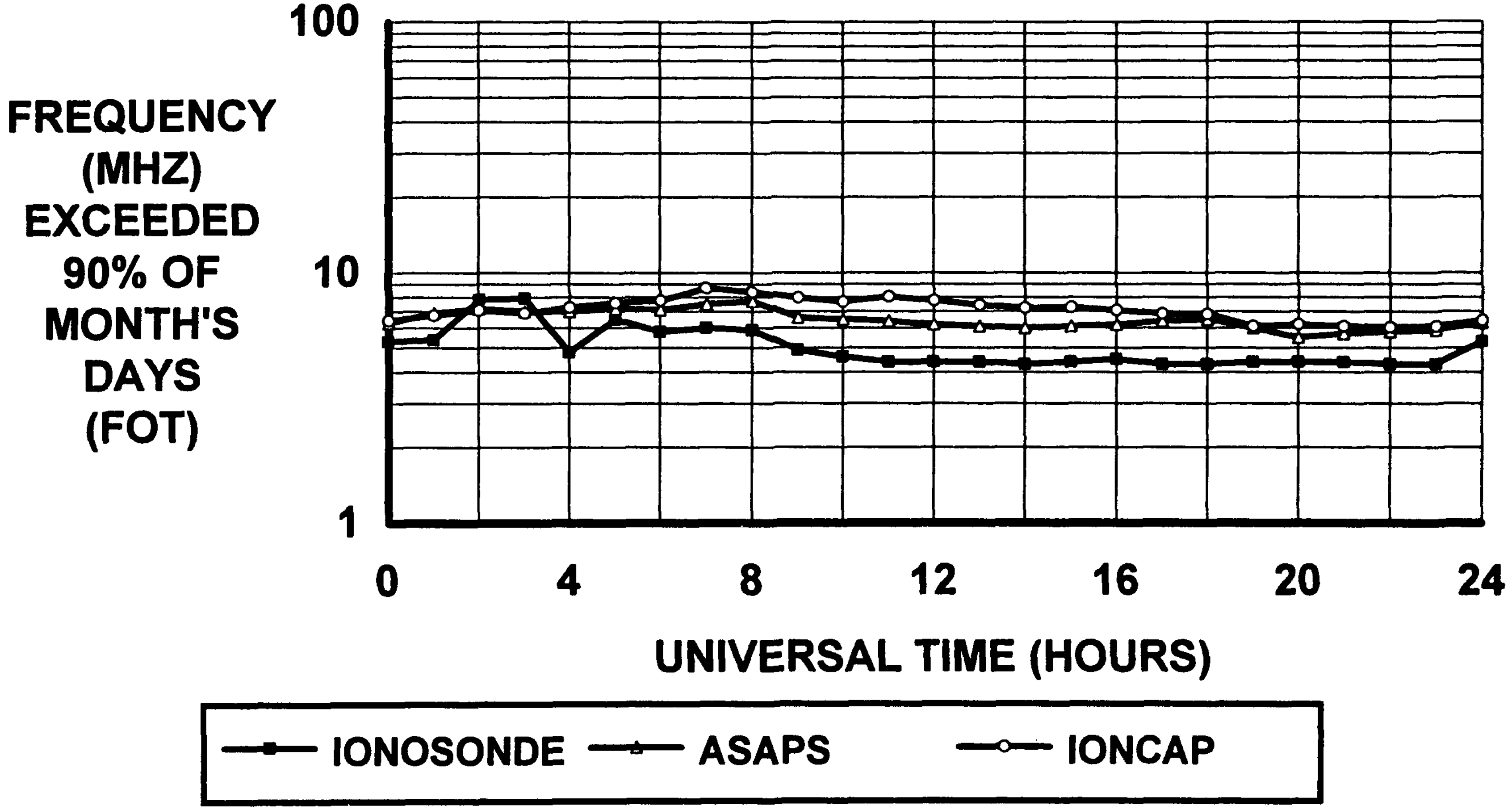


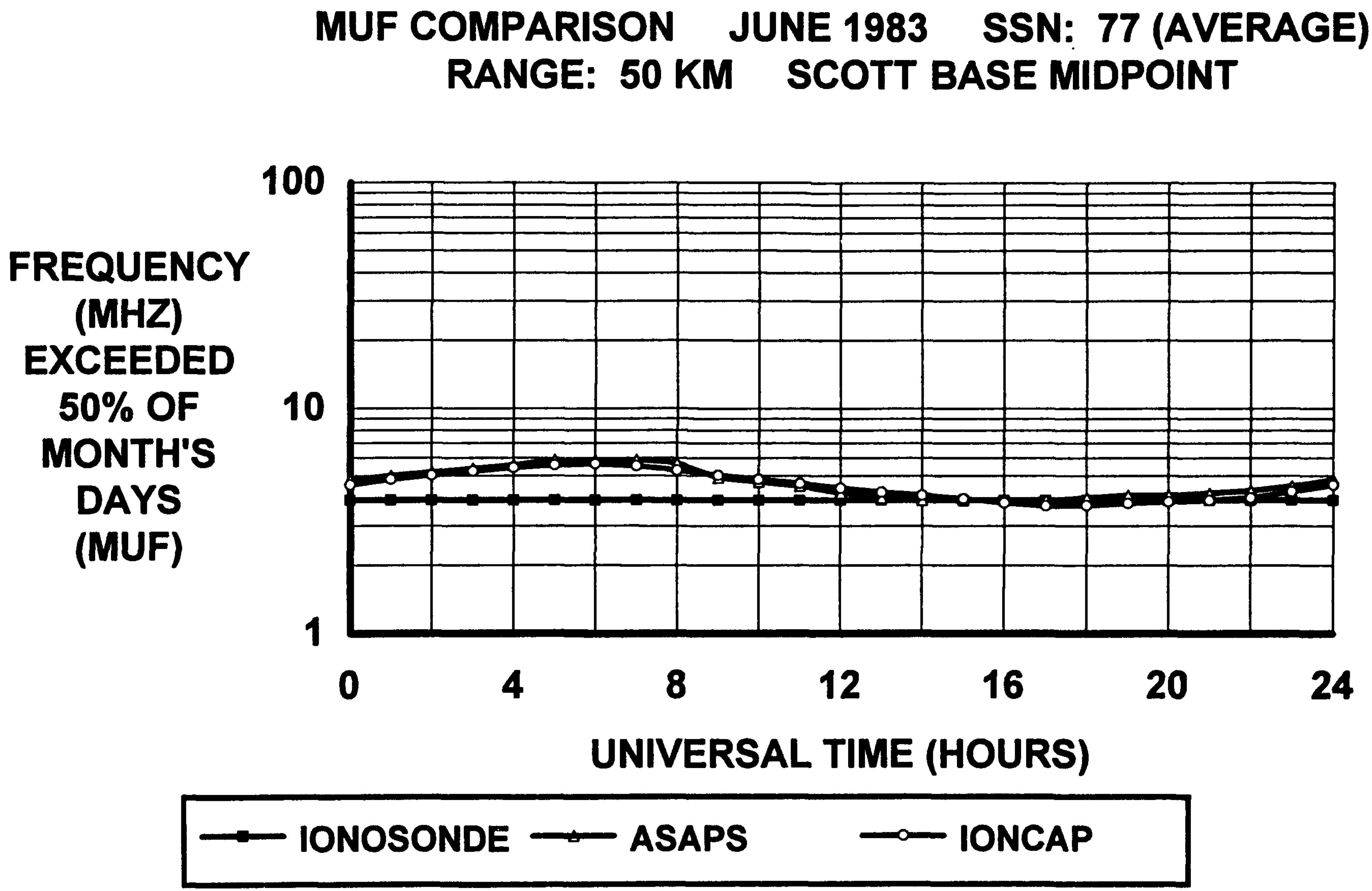
FOT COMPARISON JUNE 1983 SSN: 77 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT



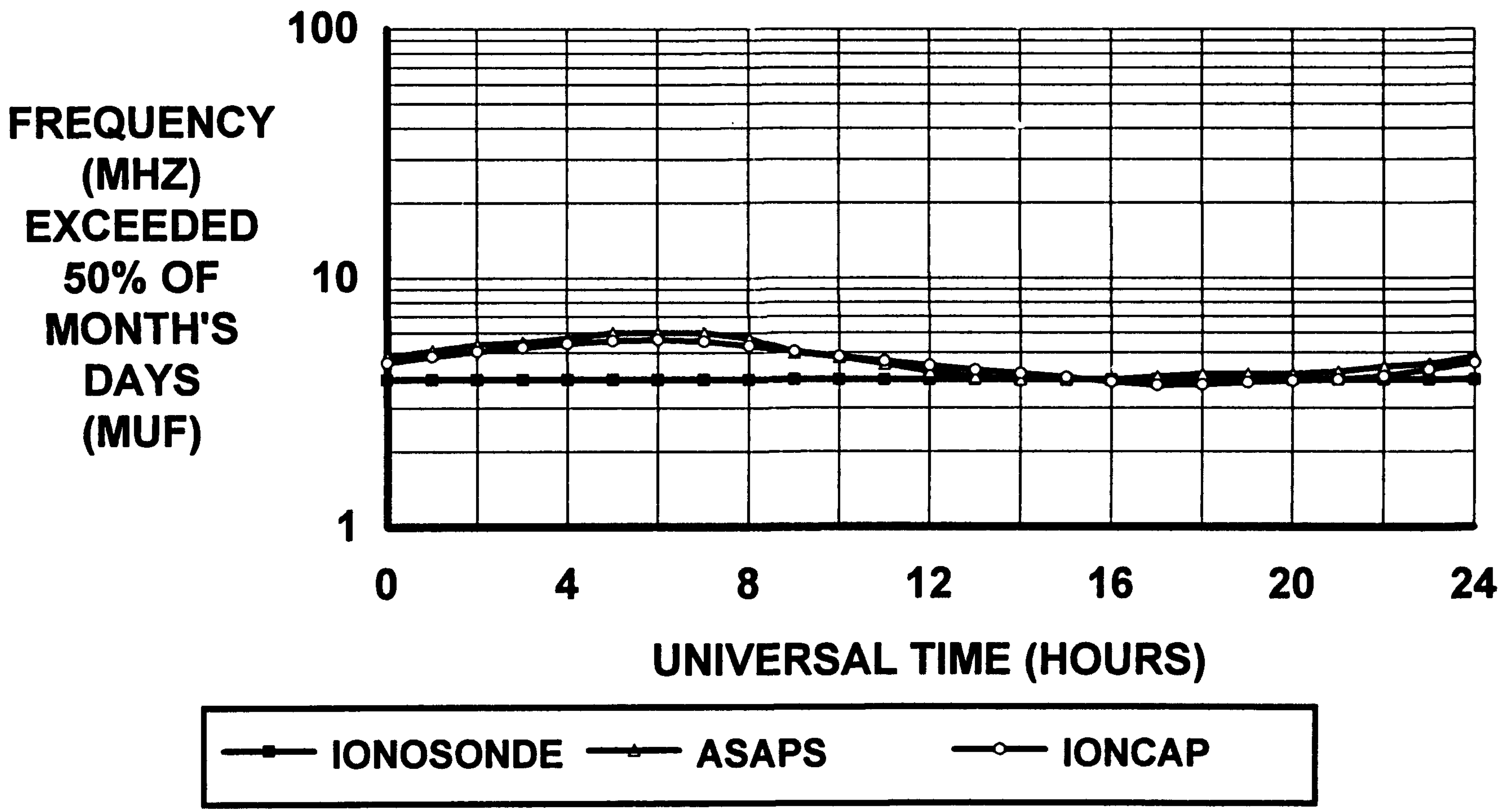

FOT COMPARISON JUNE 1983 SSN: 77 (AVERAGE)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

FOT COMPARISON JUNE 1983 SSN: 77 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT

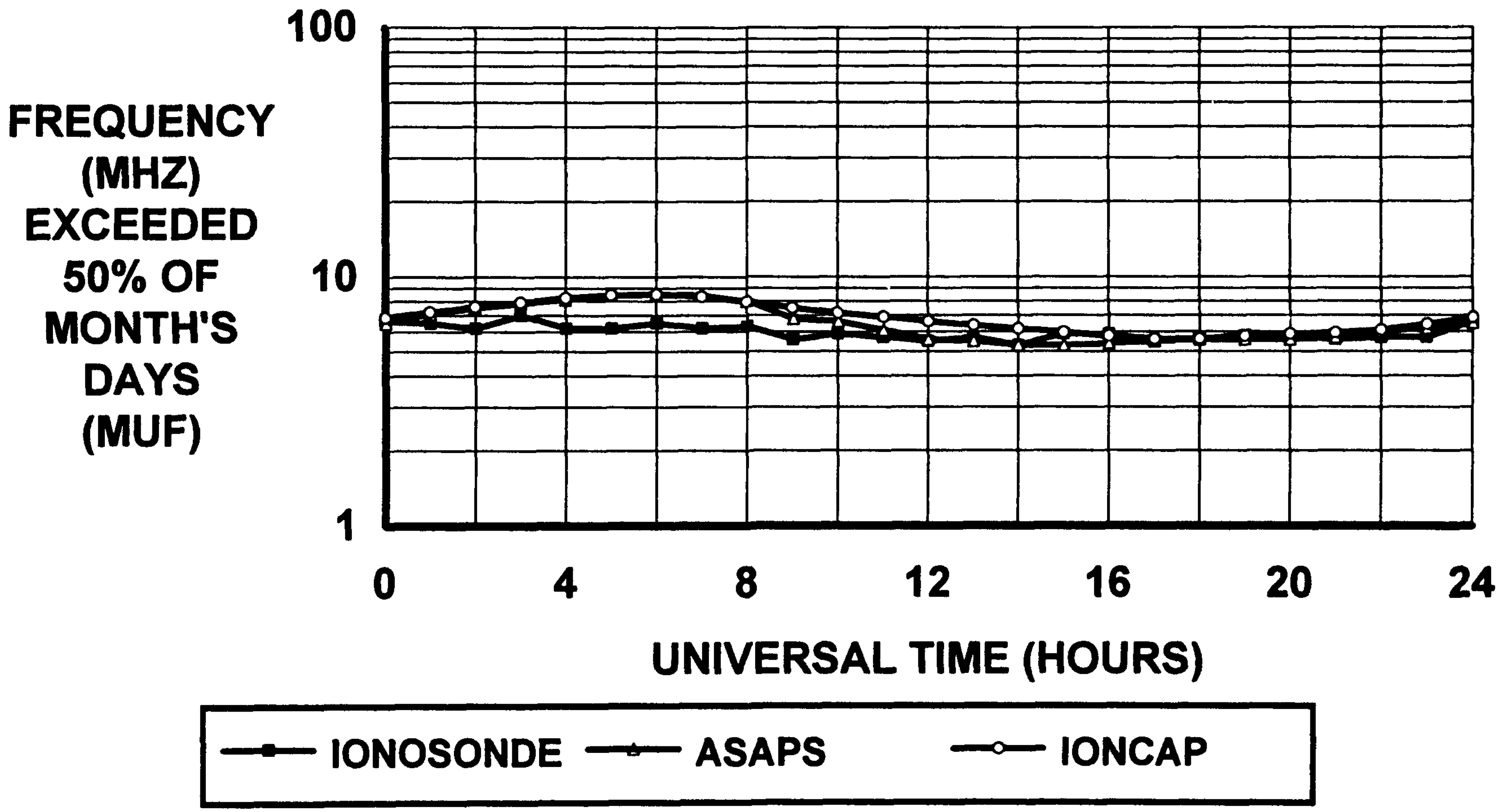


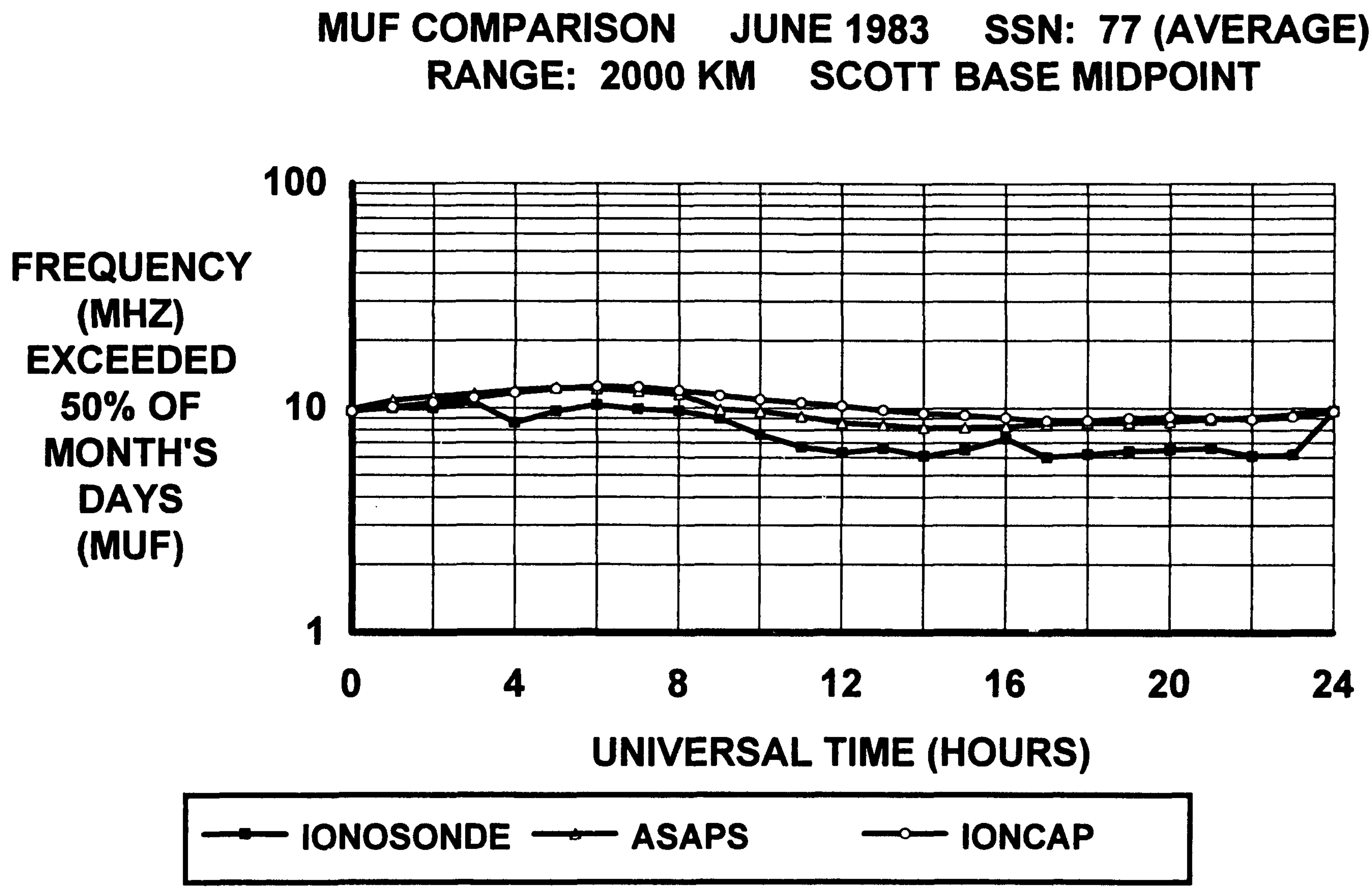

MUF COMPARISON JUNE 1983 SSN: 77 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

MUF COMPARISON JUNE 1983 SSN: 77 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT



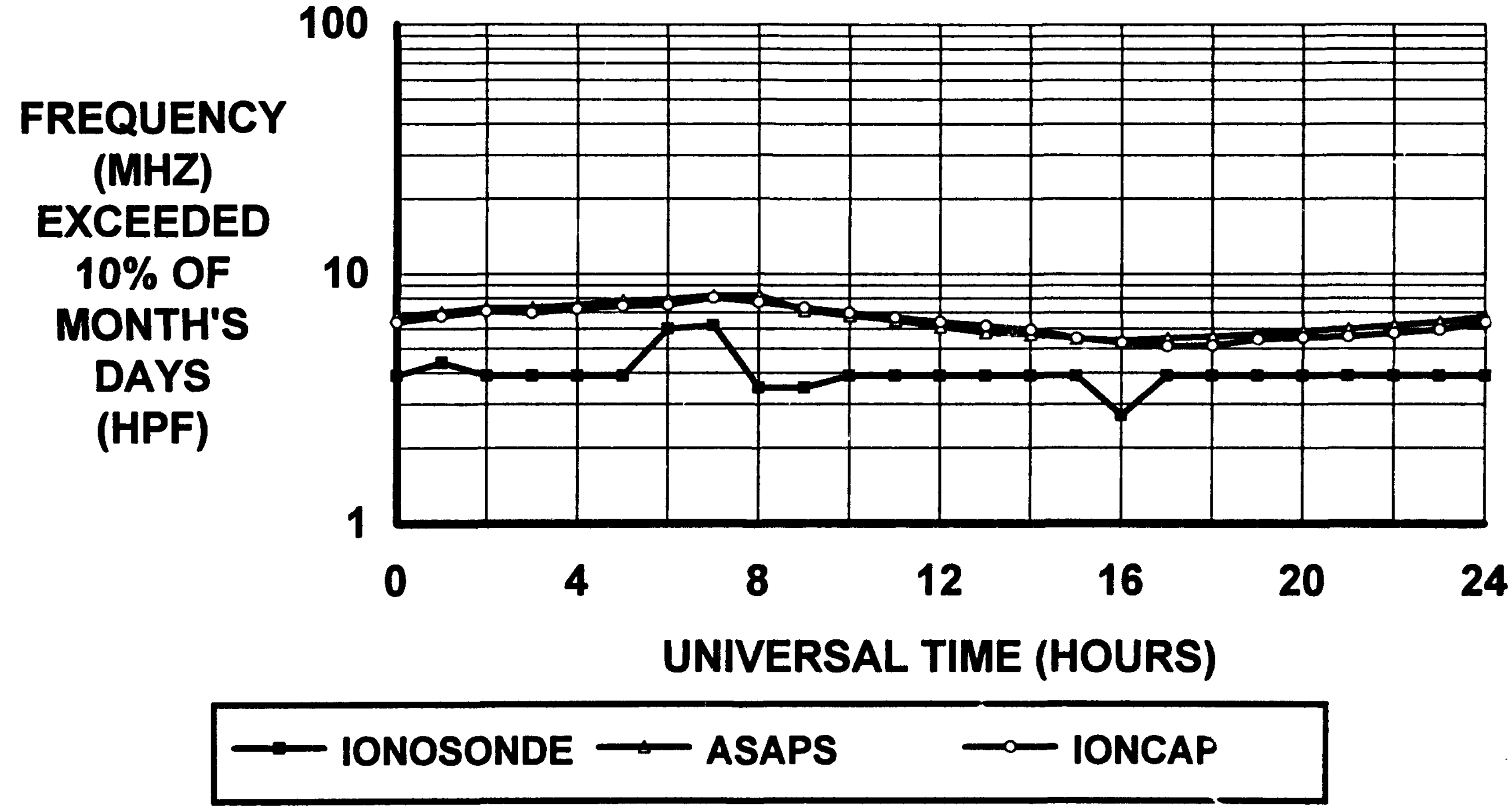
MUF COMPARISON   JUNE 1983   SSN: 77 (AVERAGE)
RANGE: 1000 KM   SCOTT BASE MIDPOINT



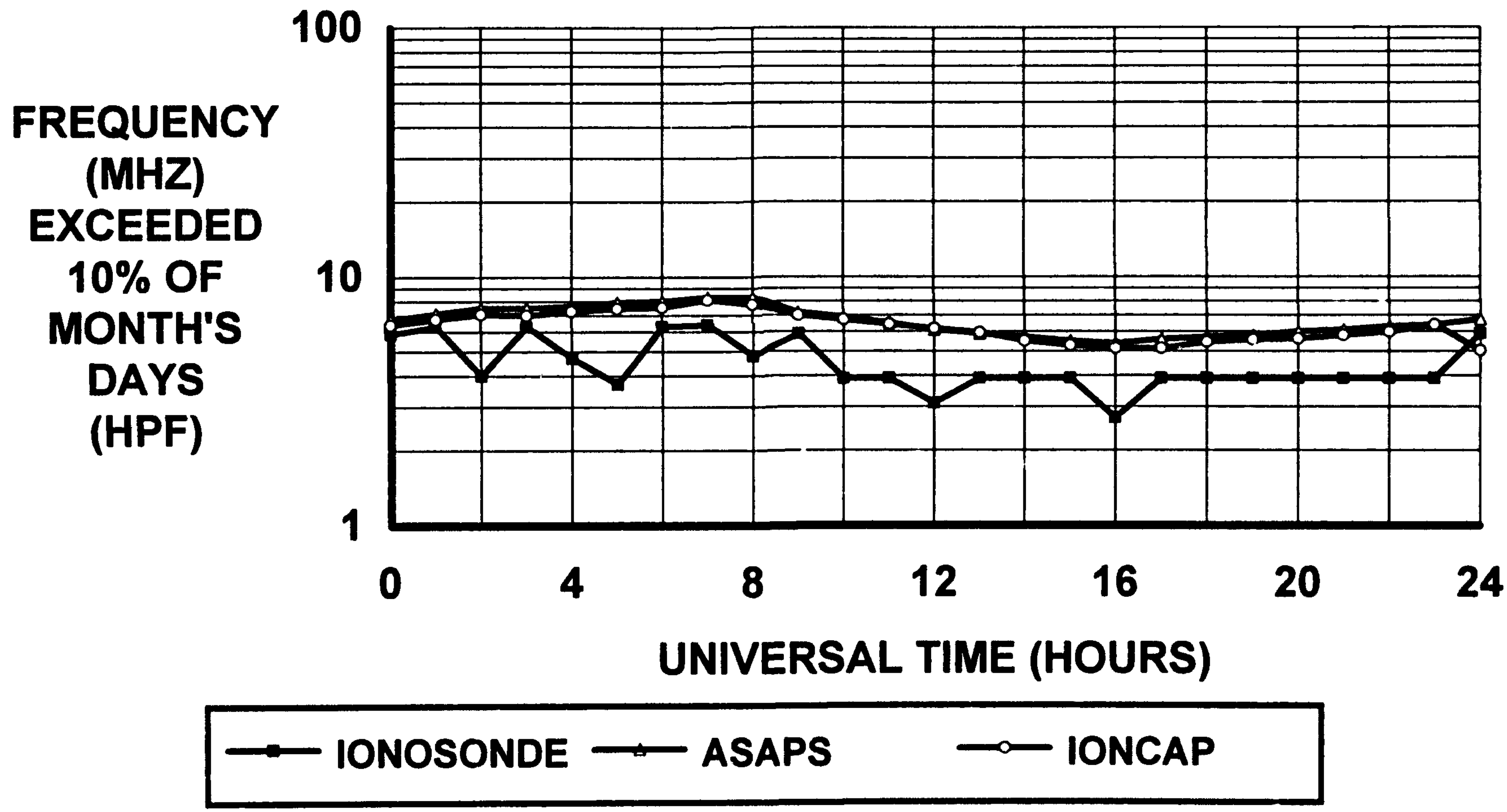


MUF COMPARISON JUNE 1983 SSN: 77 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

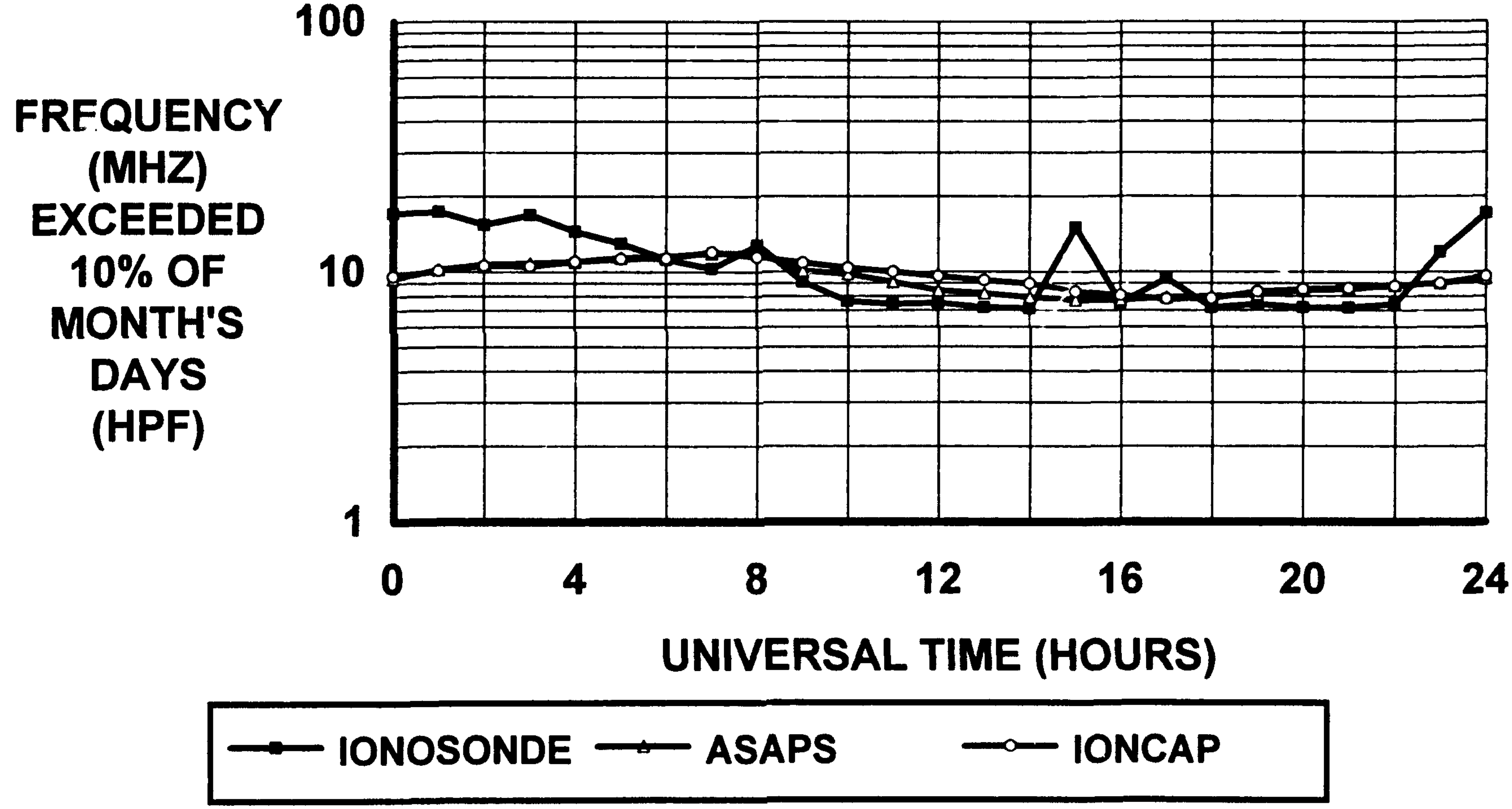
HPF COMPARISON JUNE 1983 SSN: 77 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT



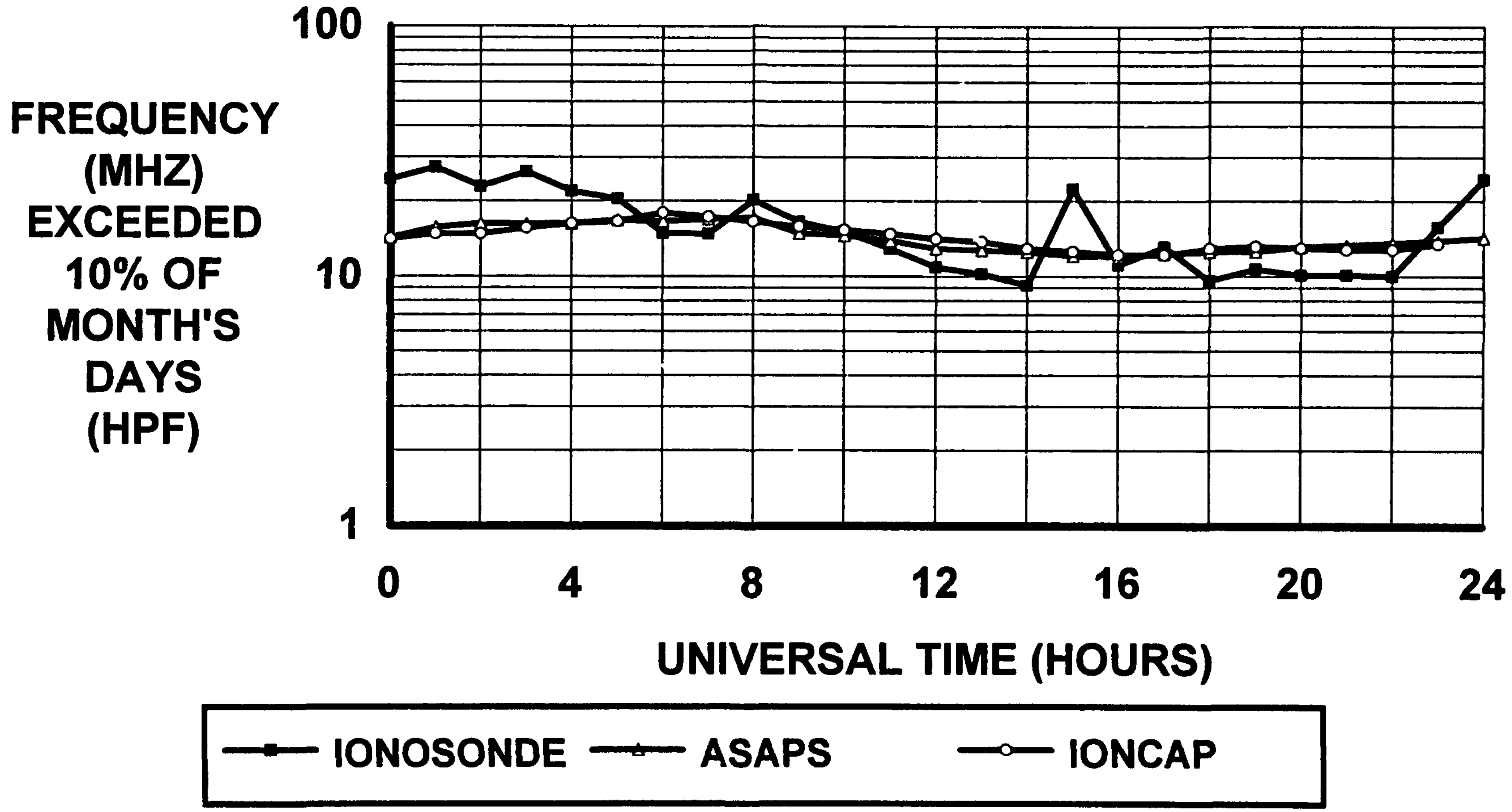
HPF COMPARISON JUNE 1983 SSN: 77 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT



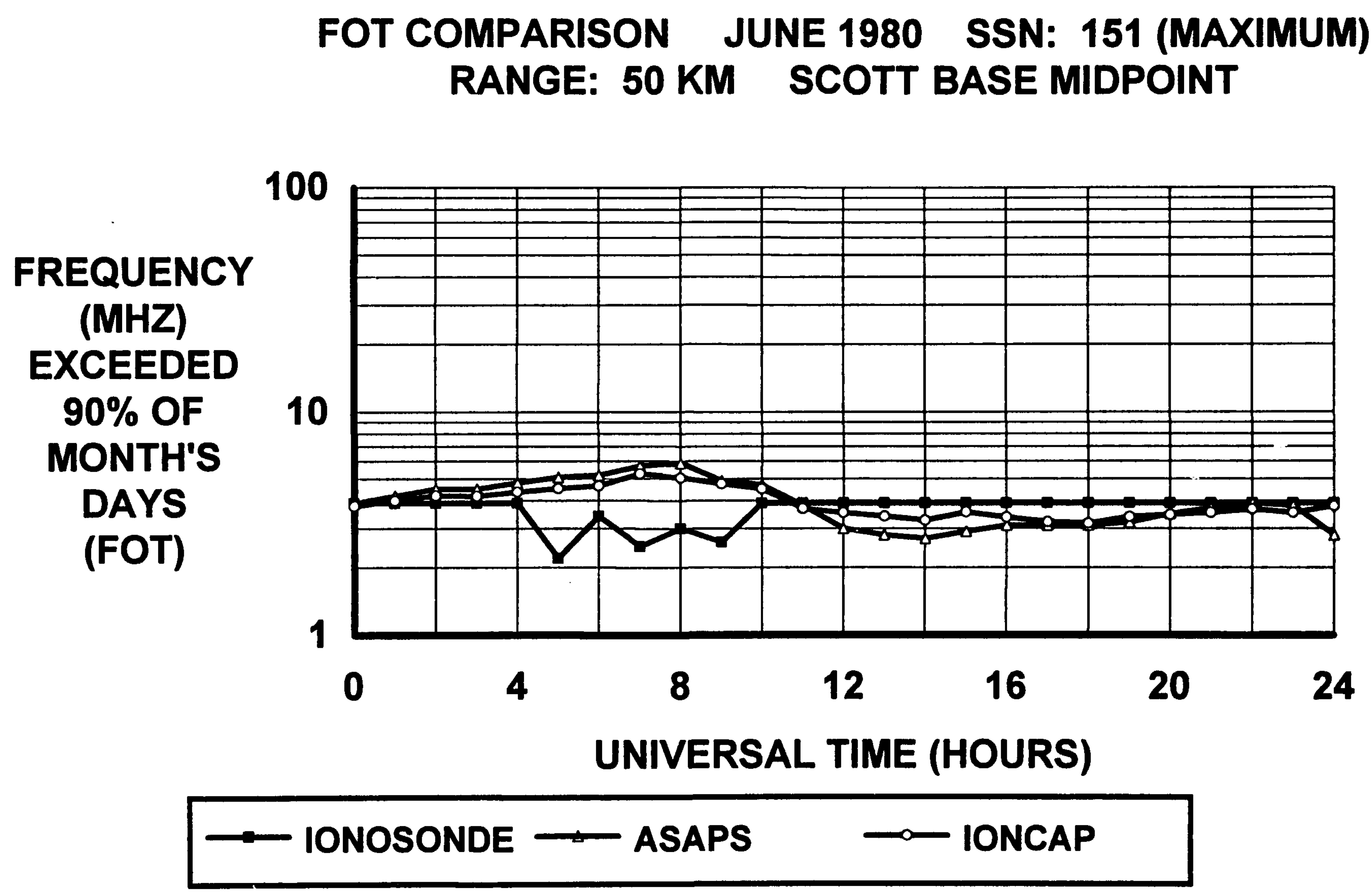
HPF COMPARISON JUNE 1983 SSN: 77 (AVERAGE)
RANGE: 1000 KM SCOTT BASE MIDPOINT



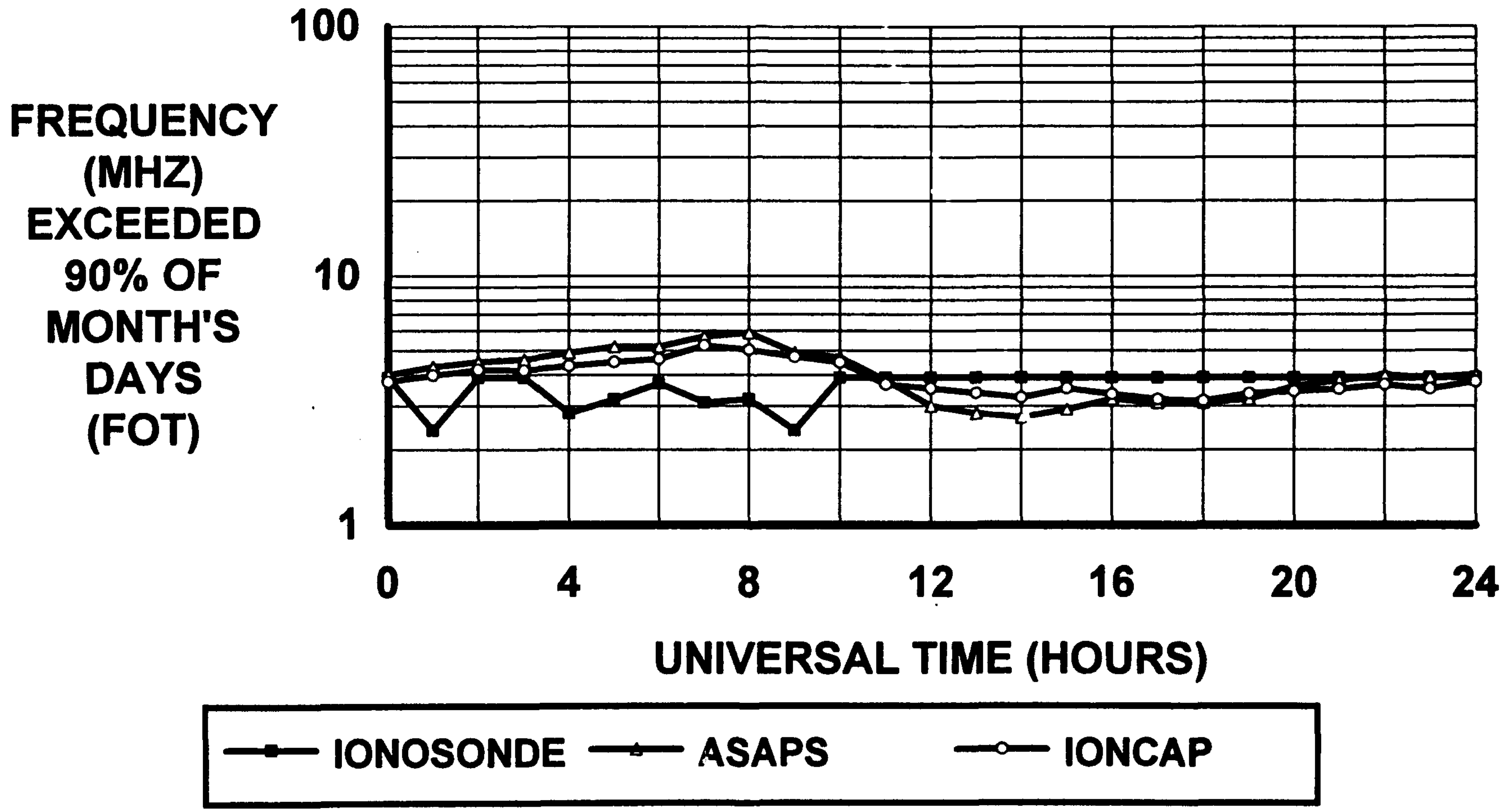
HPF COMPARISON JUNE 1983 SSN: 77 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT

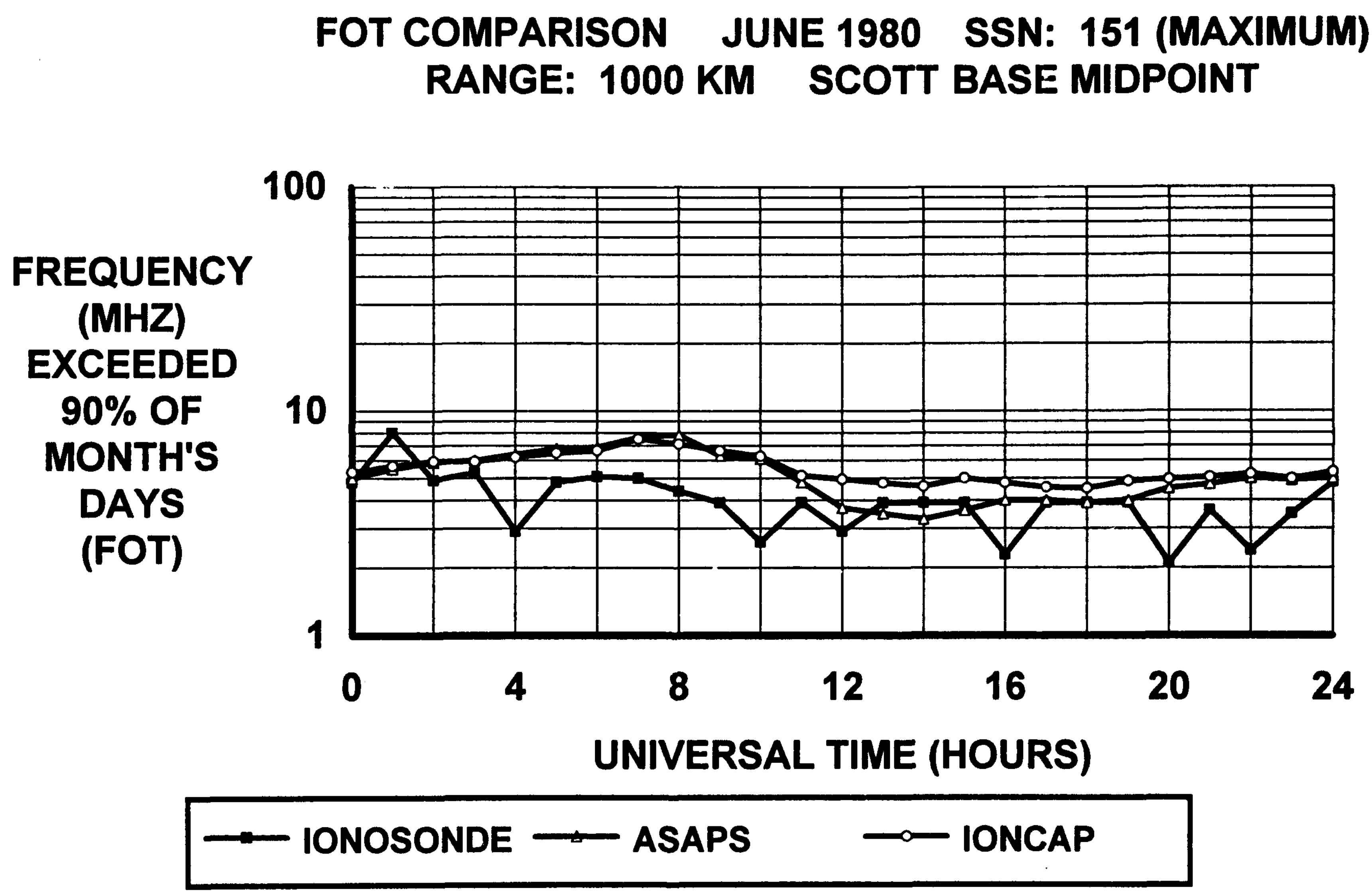


		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

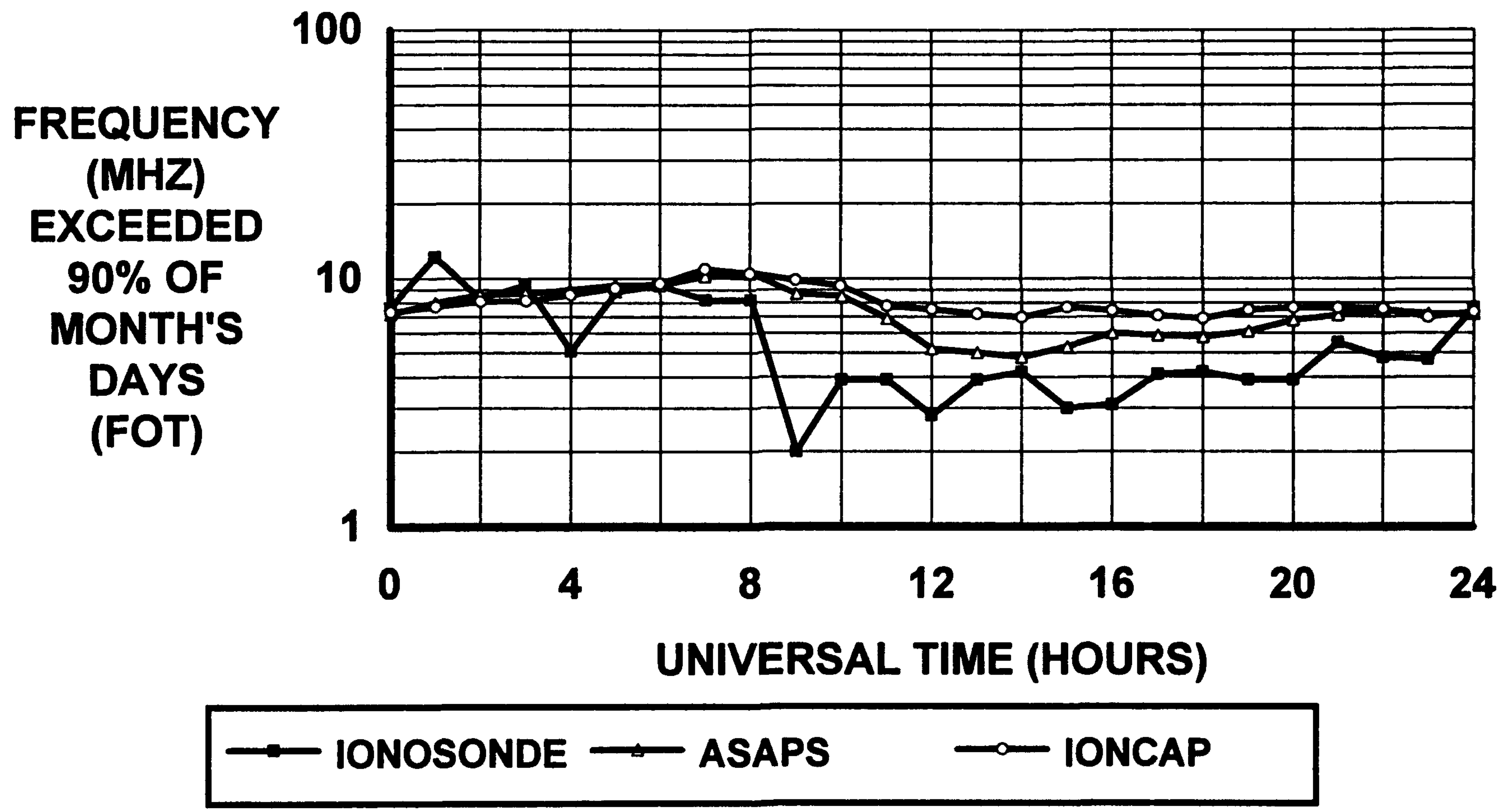

FOT COMPARISON JUNE 1980 SSN: 151 (MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

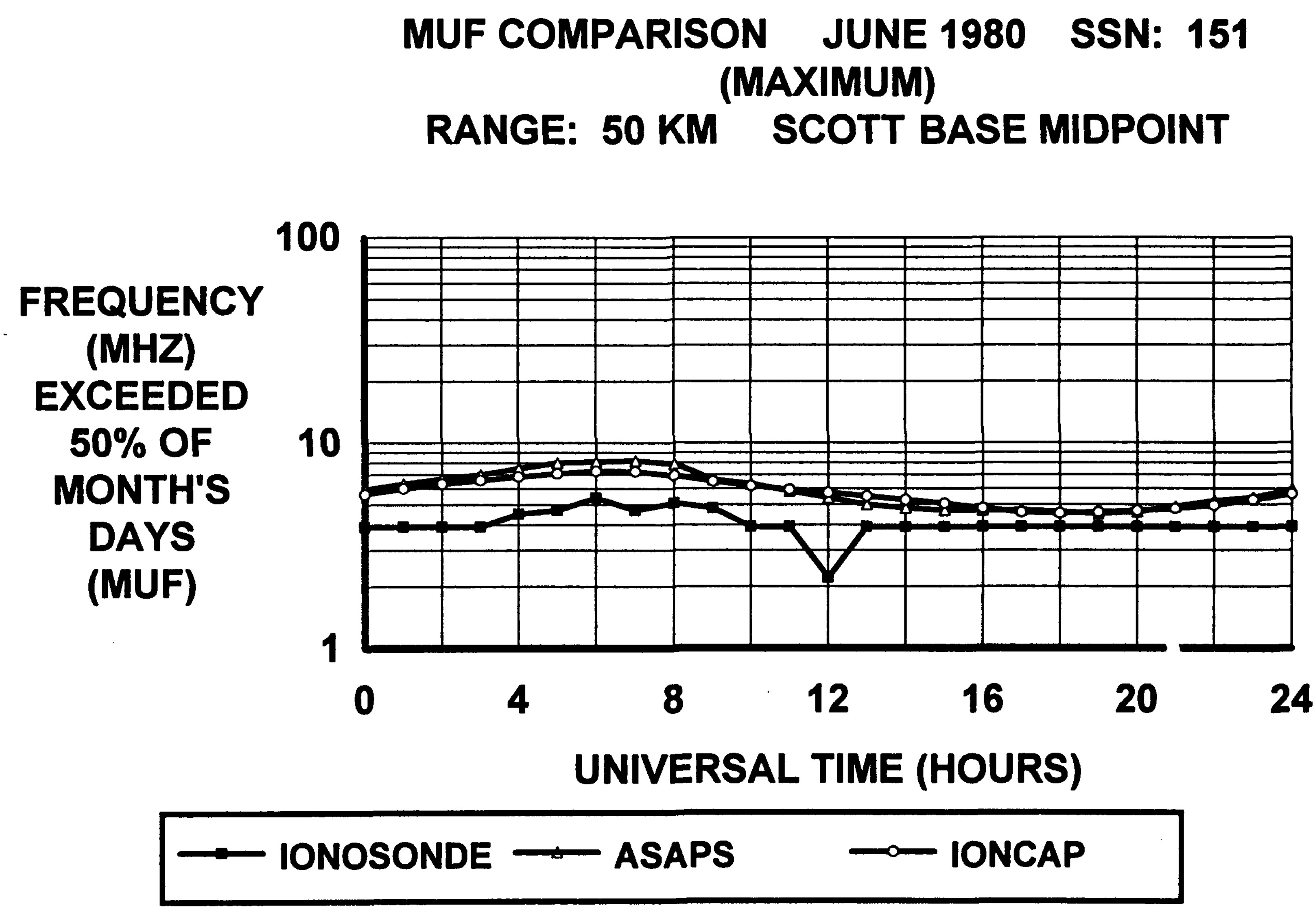
FOT COMPARISON JUNE 1980 SSN: 151 (MAXIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT



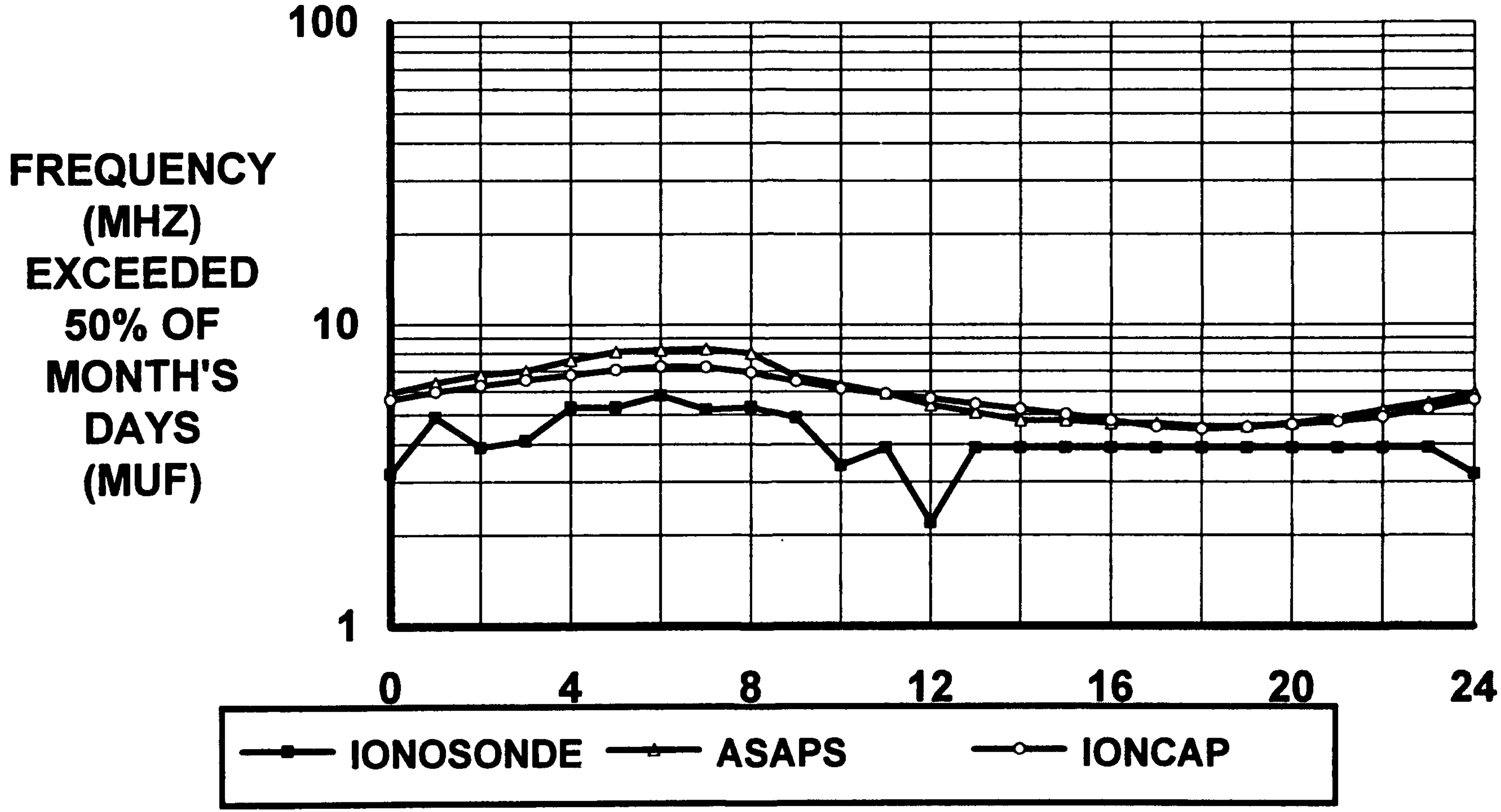

FOT COMPARISON JUNE 1980 SSN: 151 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

FOT COMPARISON   JUNE 1980   SSN: 151 (MAXIMUM)
RANGE: 2000 KM   SCOTT BASE MIDPOINT

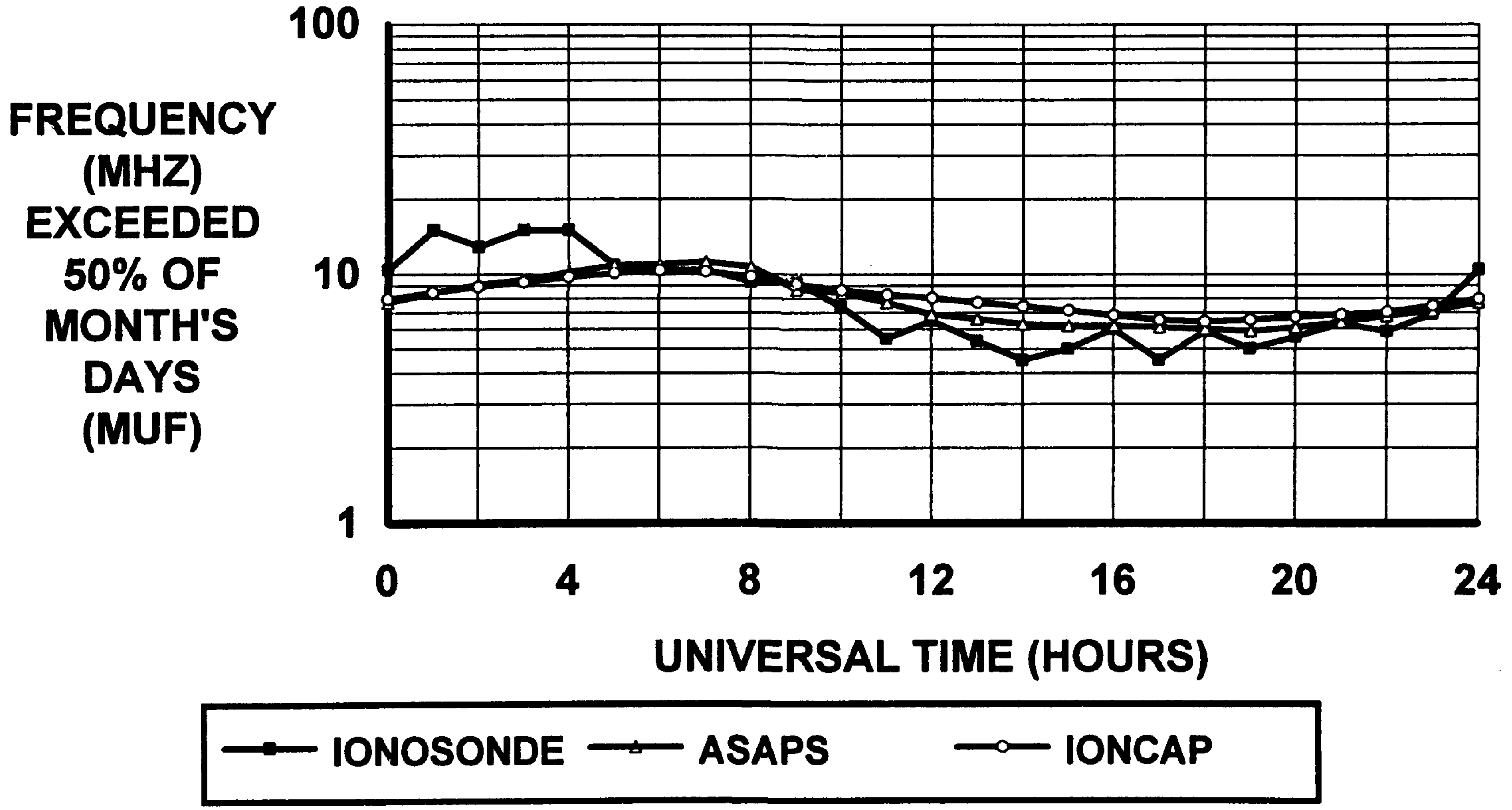



MUF COMPARISON JUNE 1980 SSN: 151
(MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

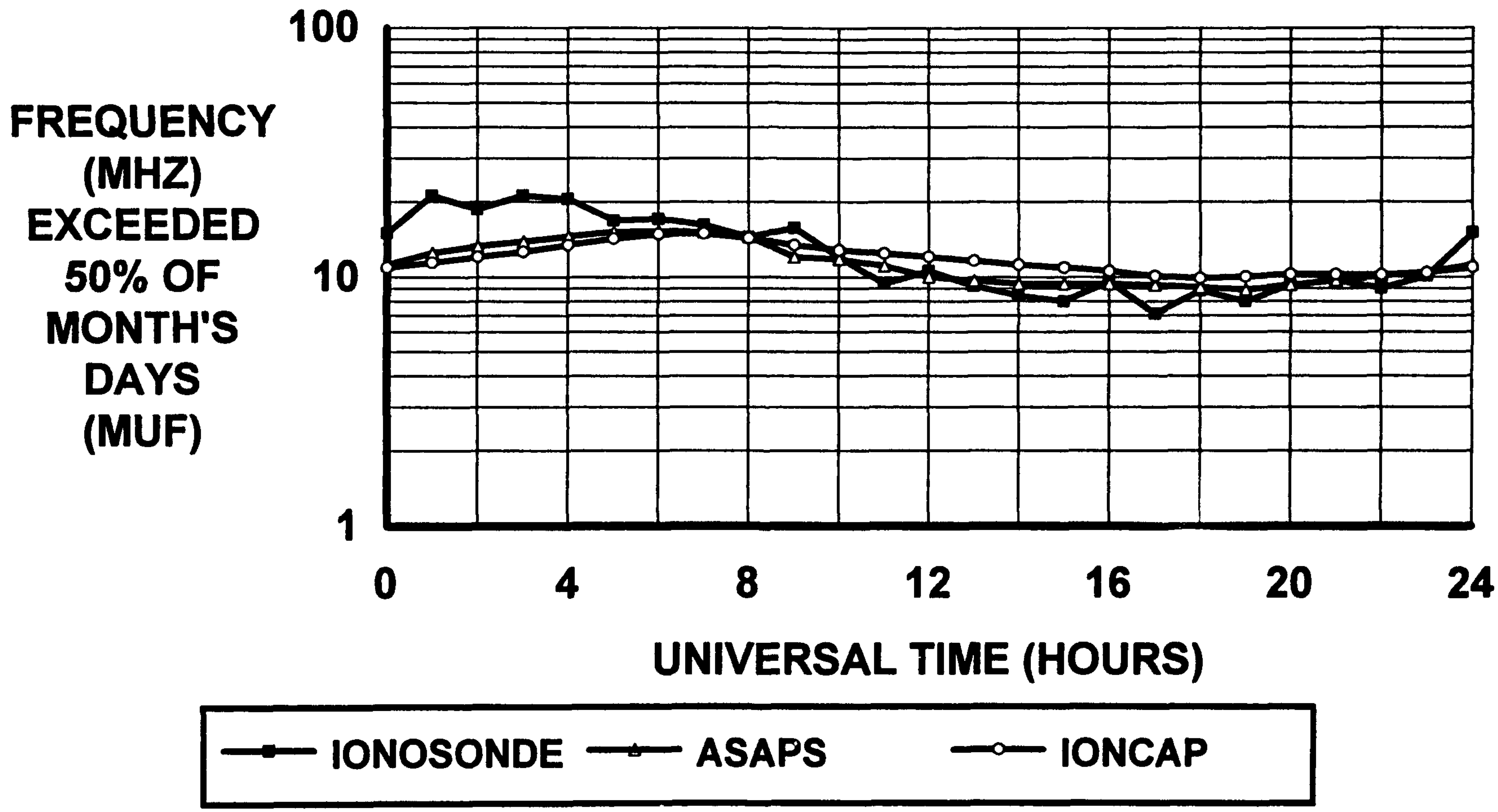
MUF COMPARISON JUNE 1980 SSN: 151 (MAXIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT



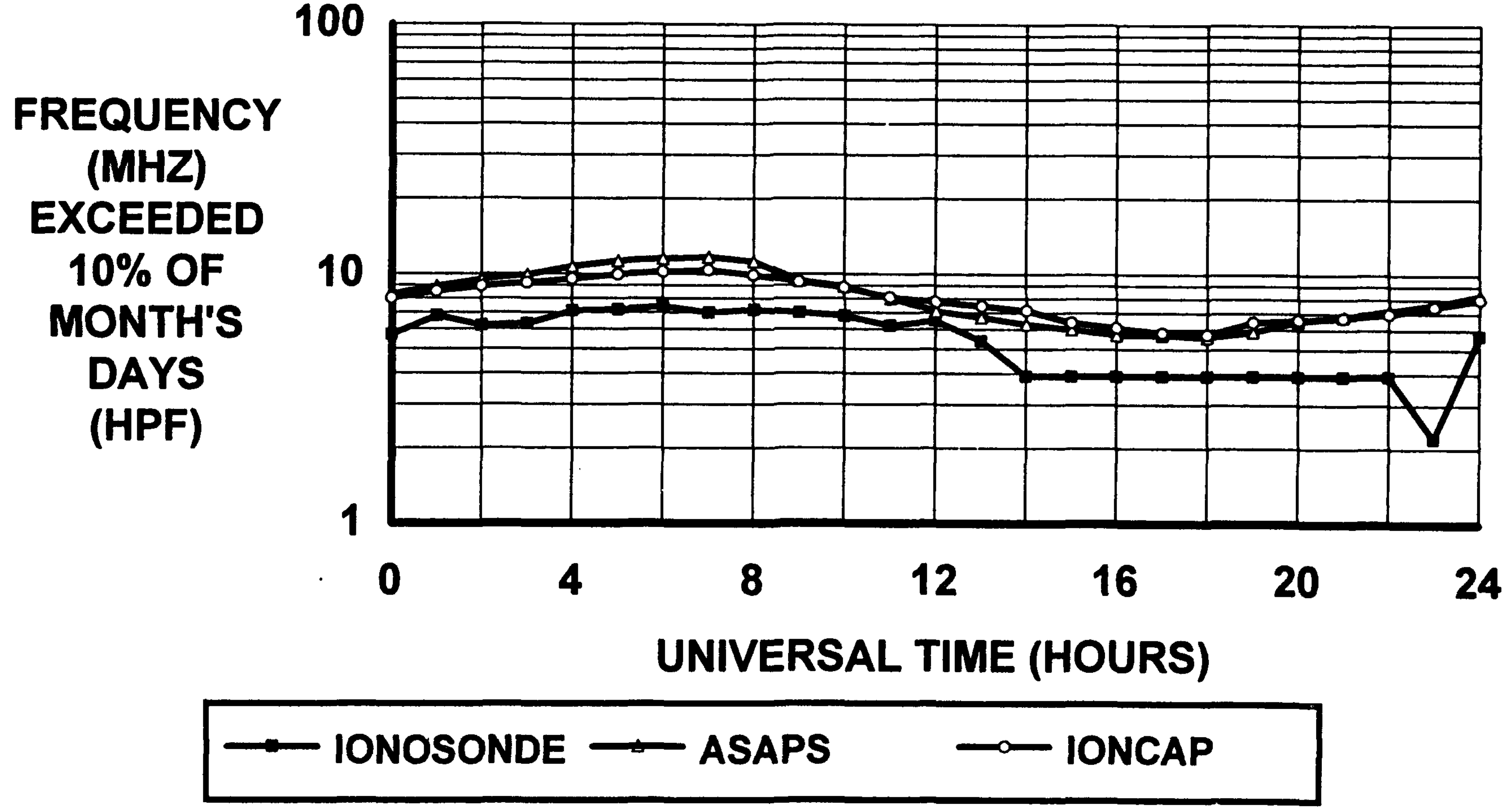
MUF COMPARISON JUNE 1980 SSN: 151 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT



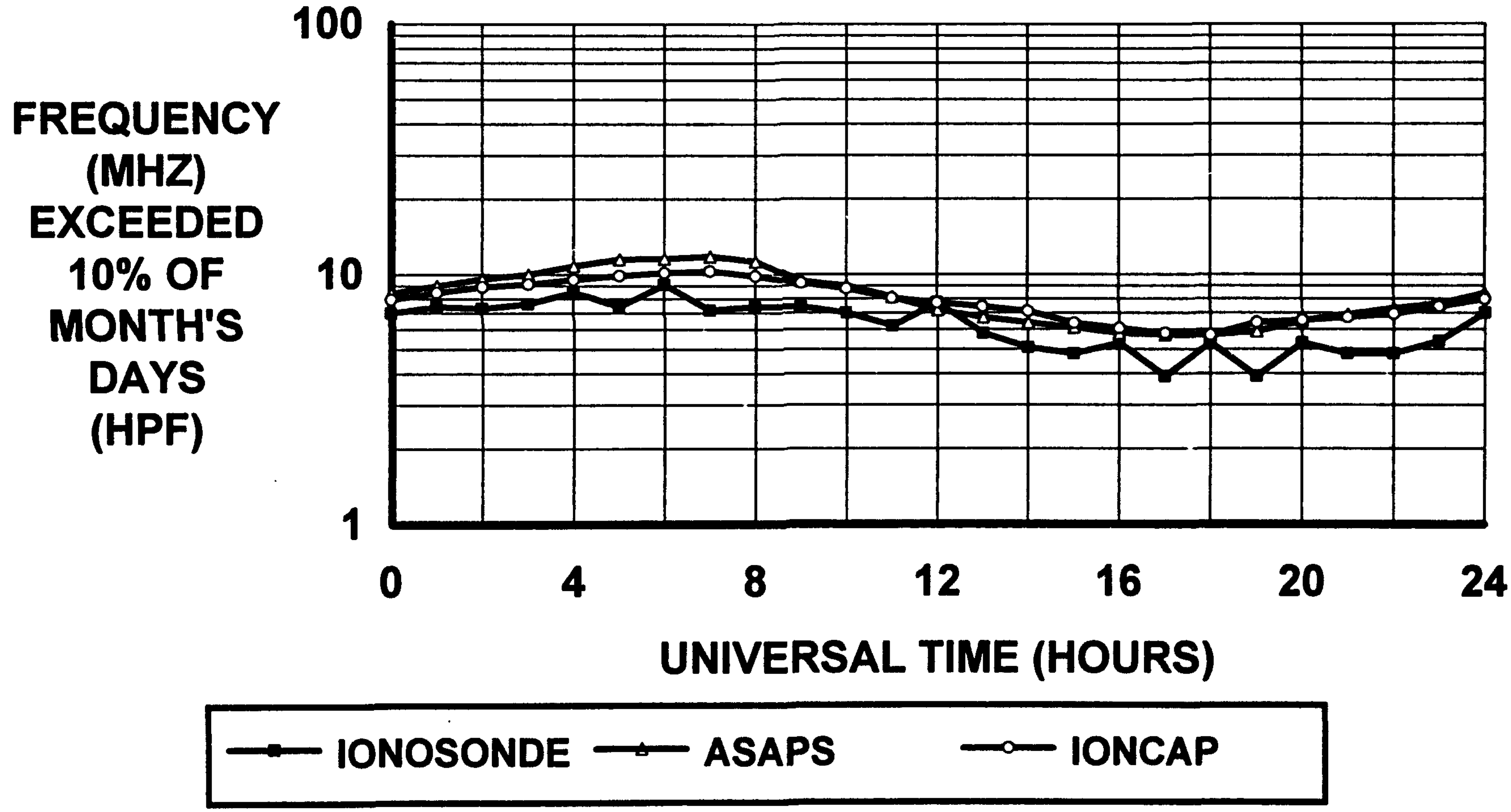
MUF COMPARISON JUNE 1980 SSN: 151 (MAXIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT

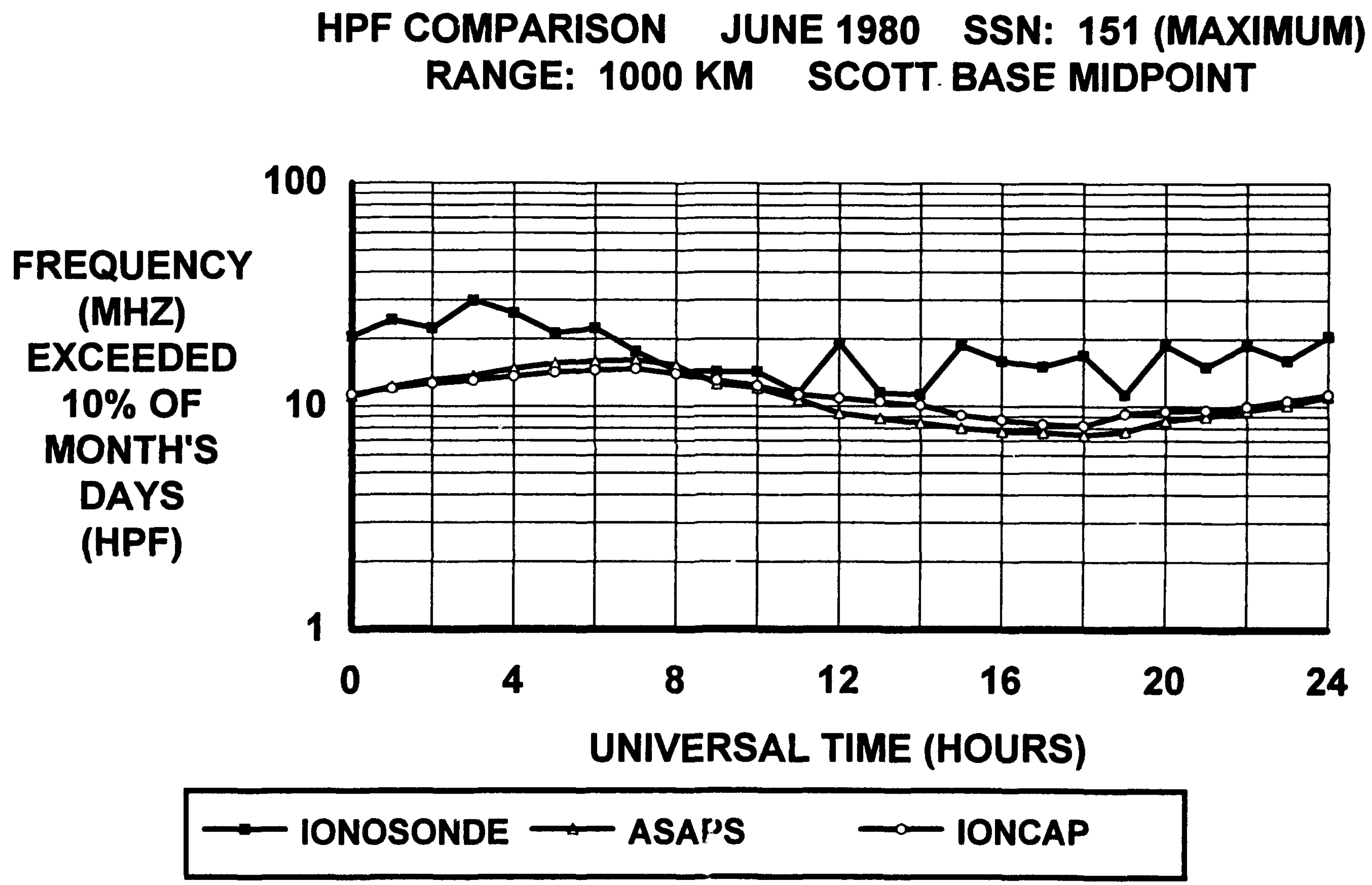


HPF COMPARISON JUNE 1980 SSN: 151 (MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT



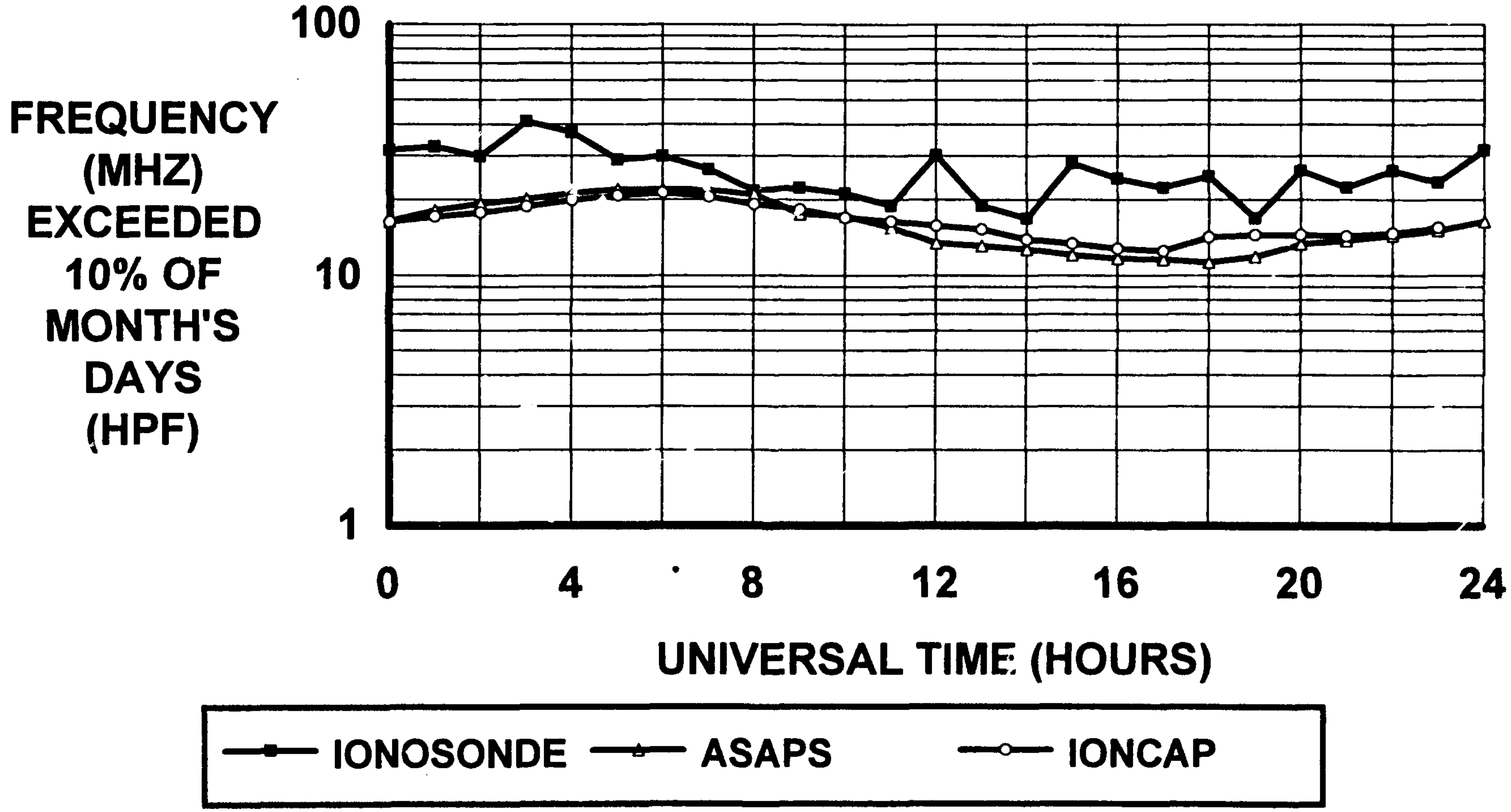
HPF COMPARISON JUNE 1980 SSN: 151 (MAXIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT



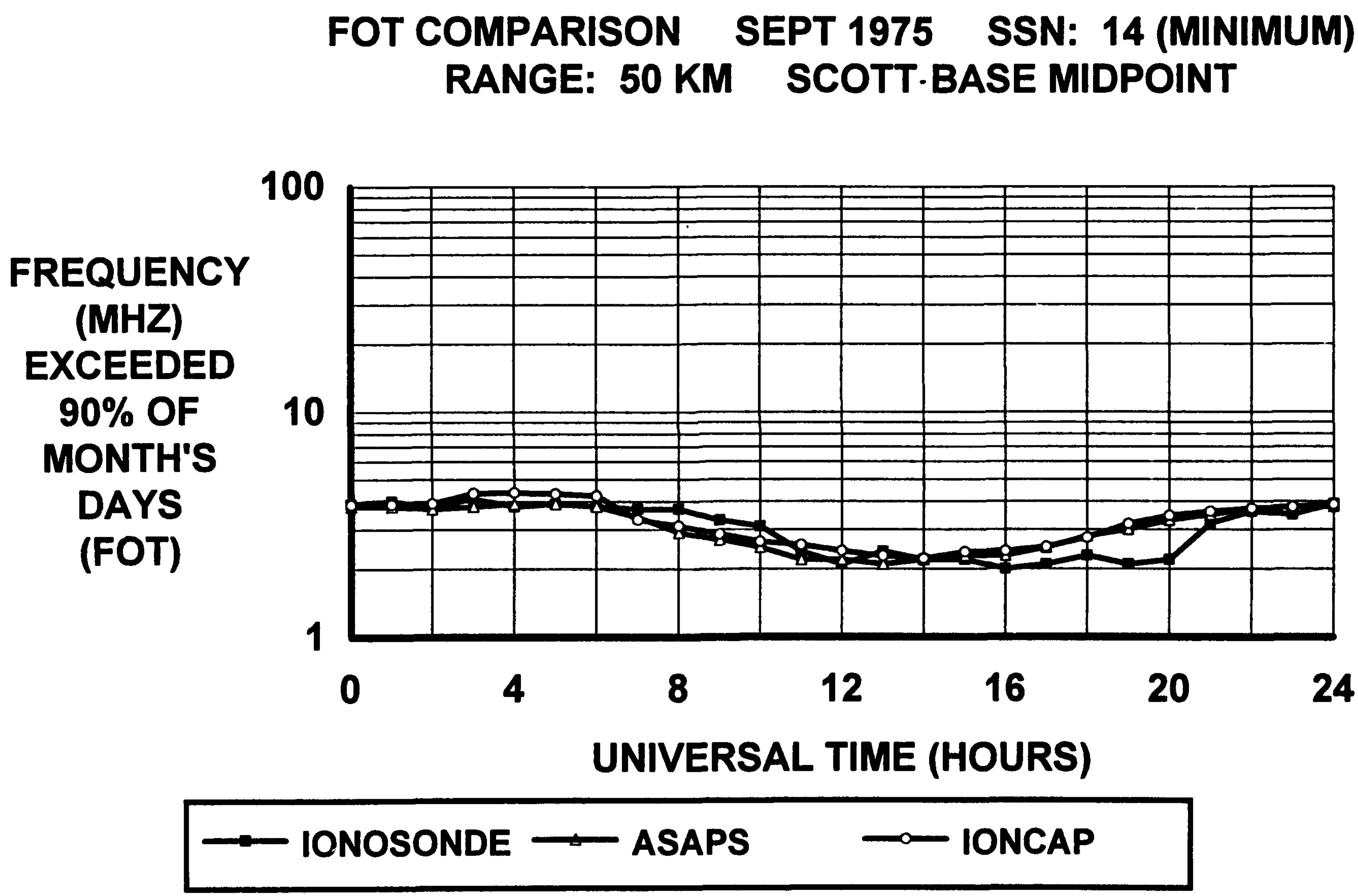


HPF COMPARISON JUNE 1980 SSN: 151 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

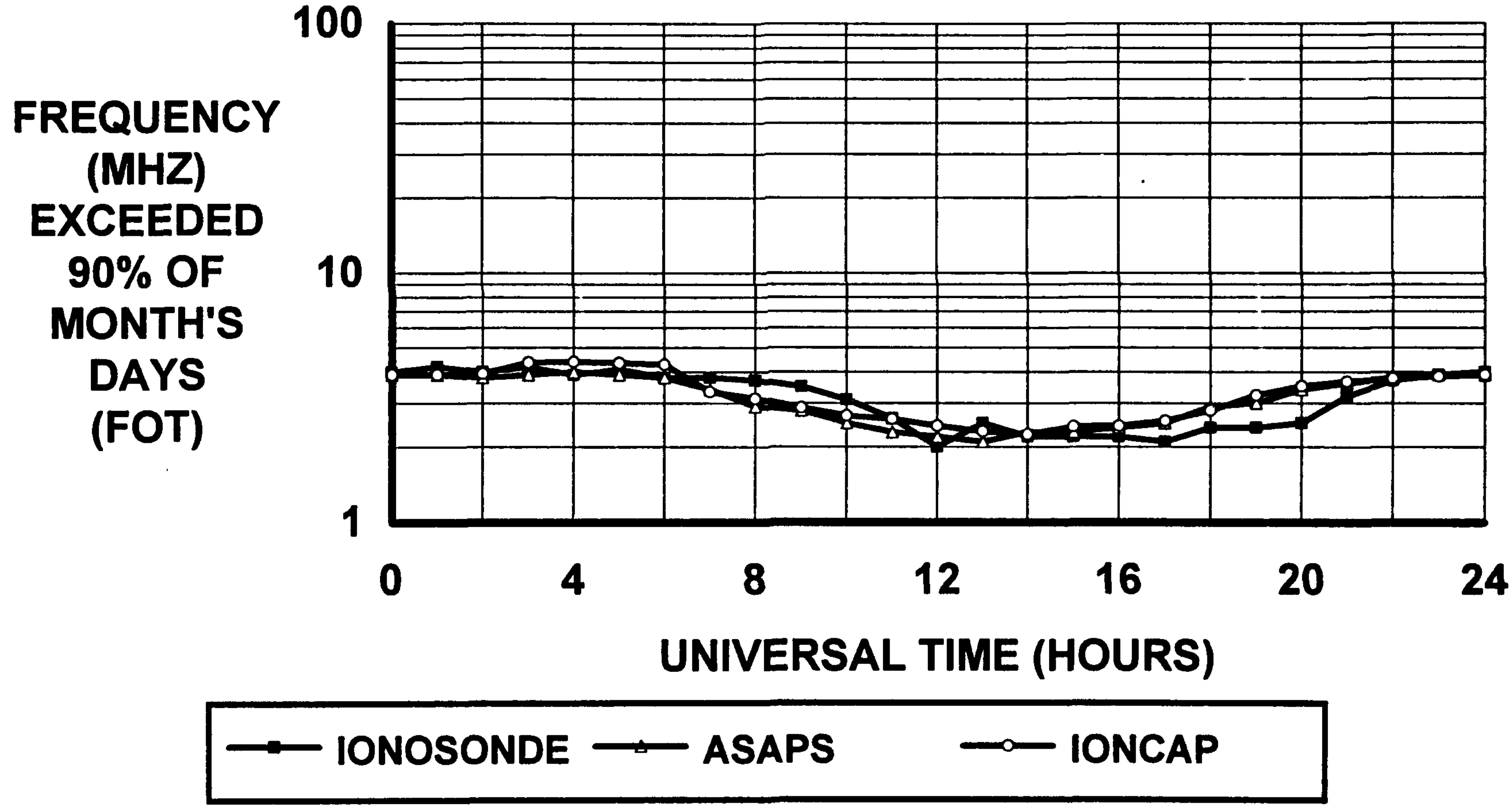
HPF COMPARISON JUNE 1980 SSN: 151 (MAXIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT

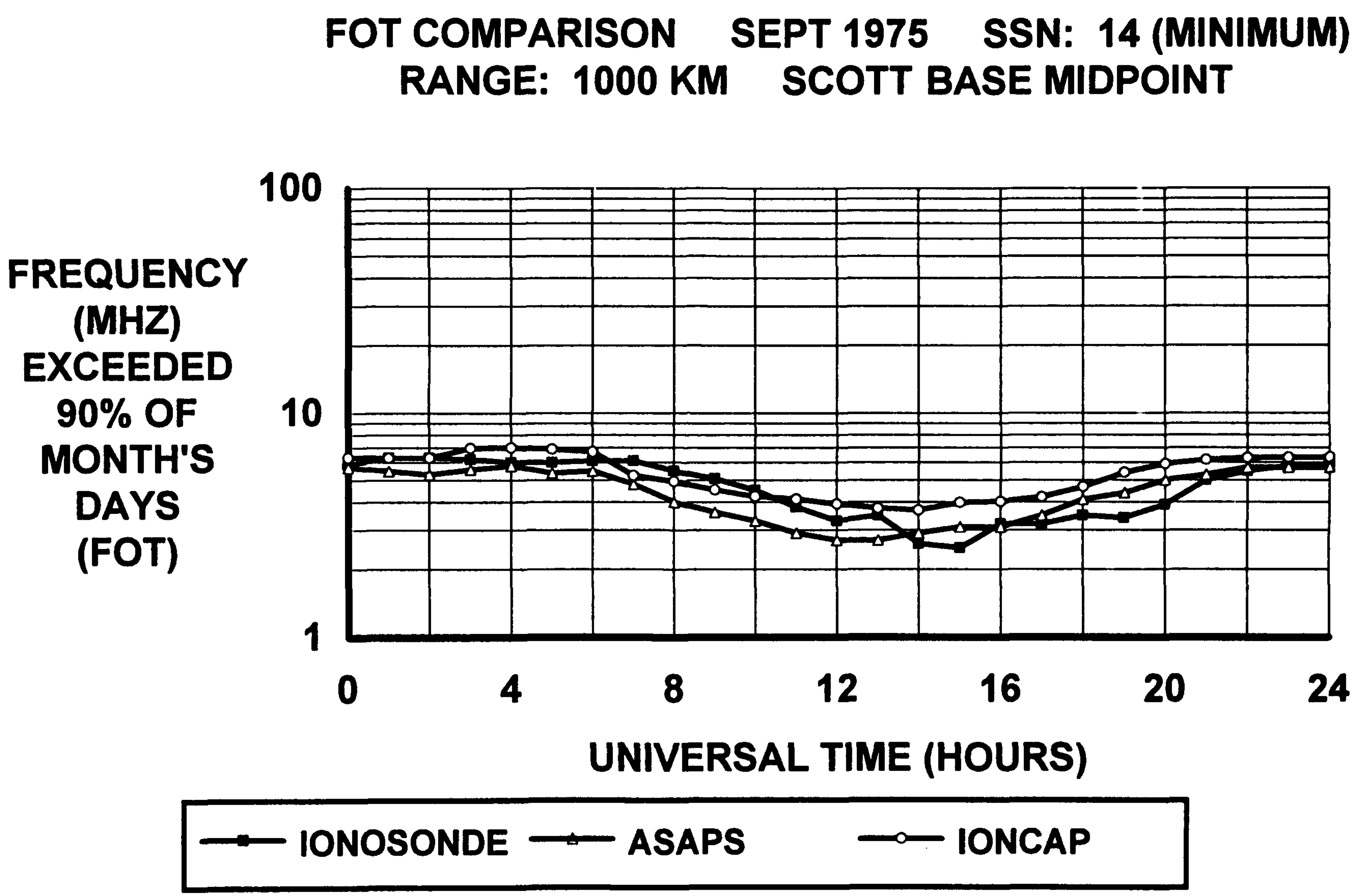


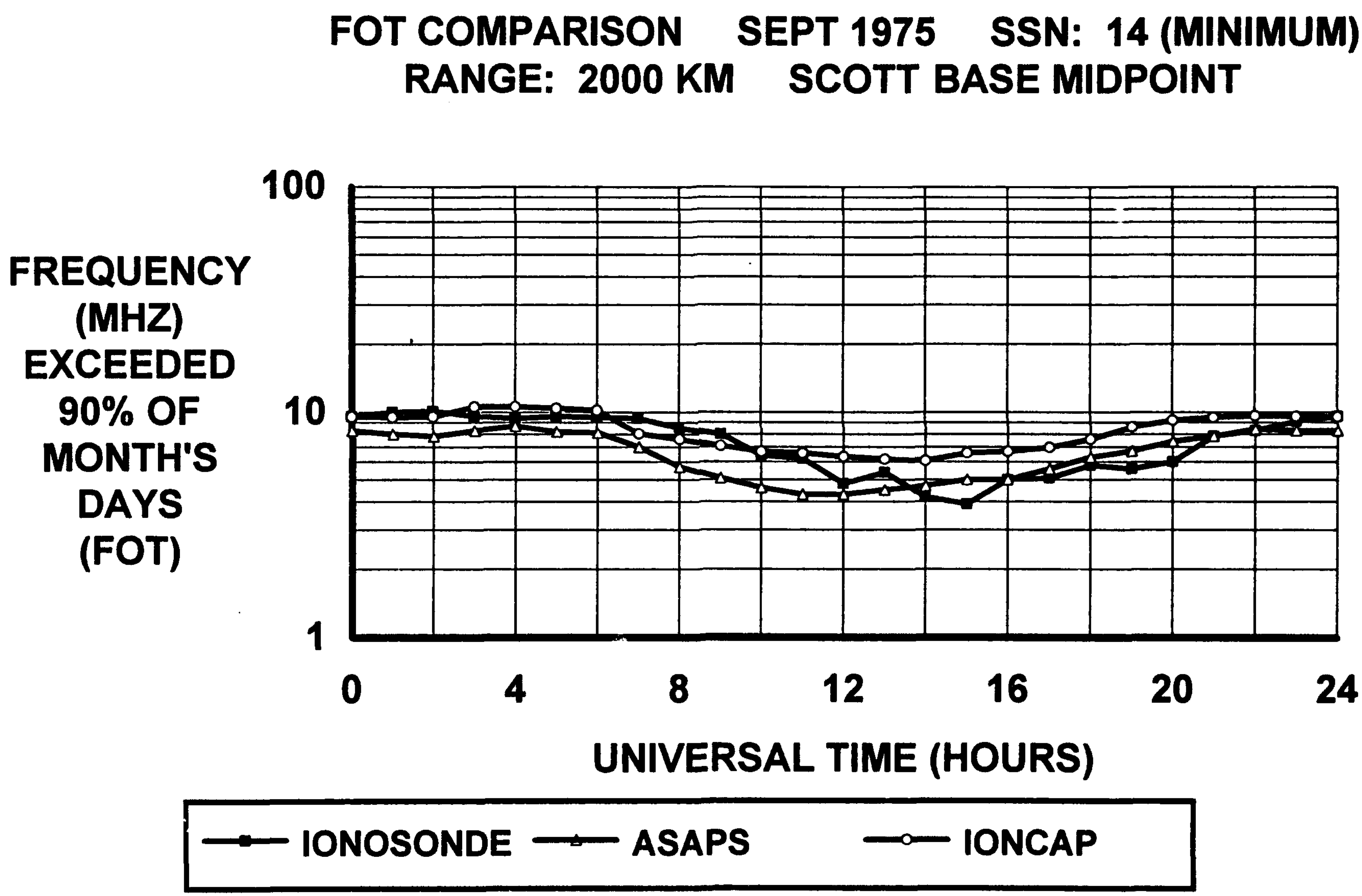
		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 / 1975	D-88 to D-91	17 / 1975	D-127 tc D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160


FOT COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 50 KM SCOTT-BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

FOT COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT

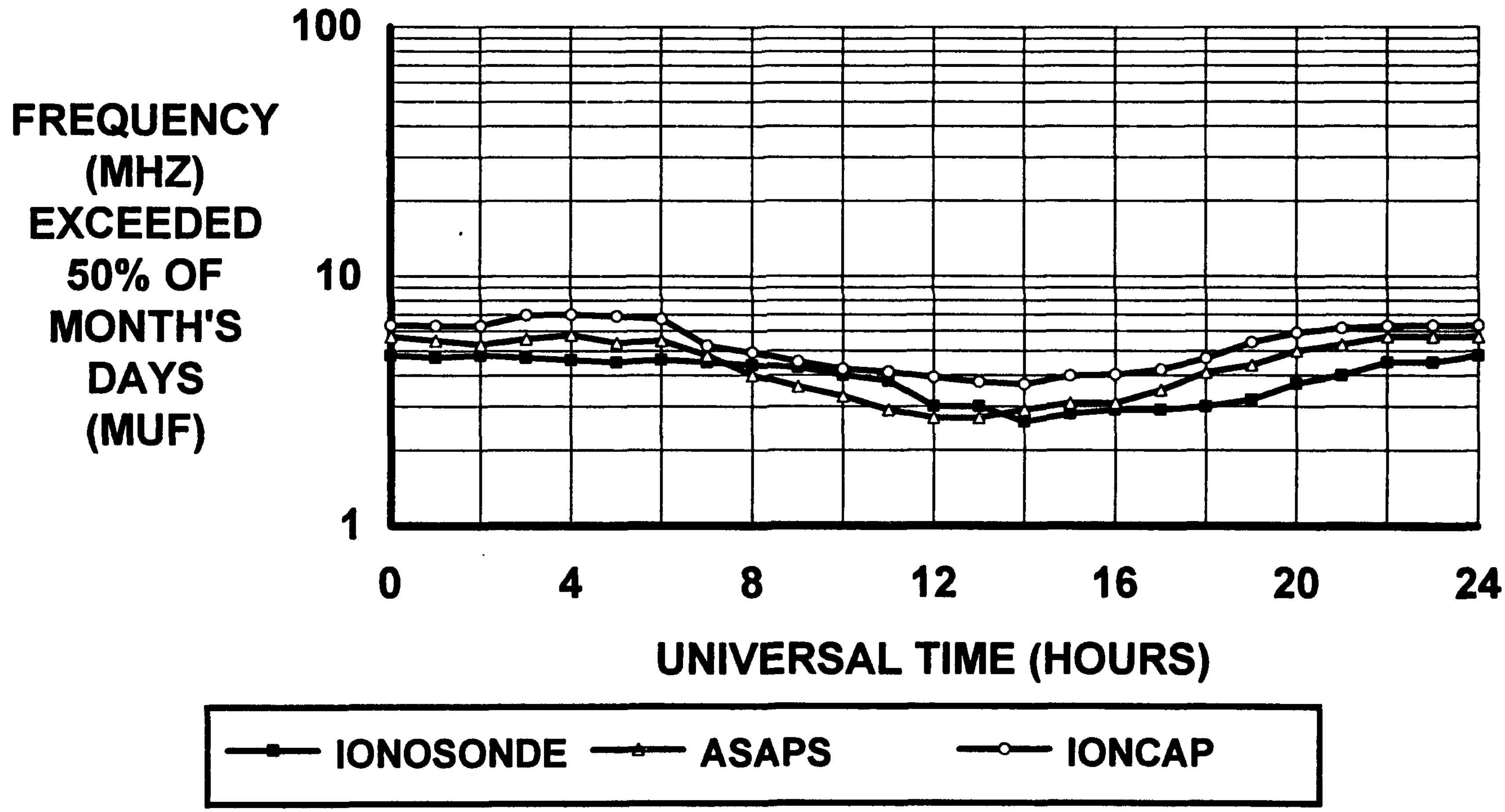



FOT COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

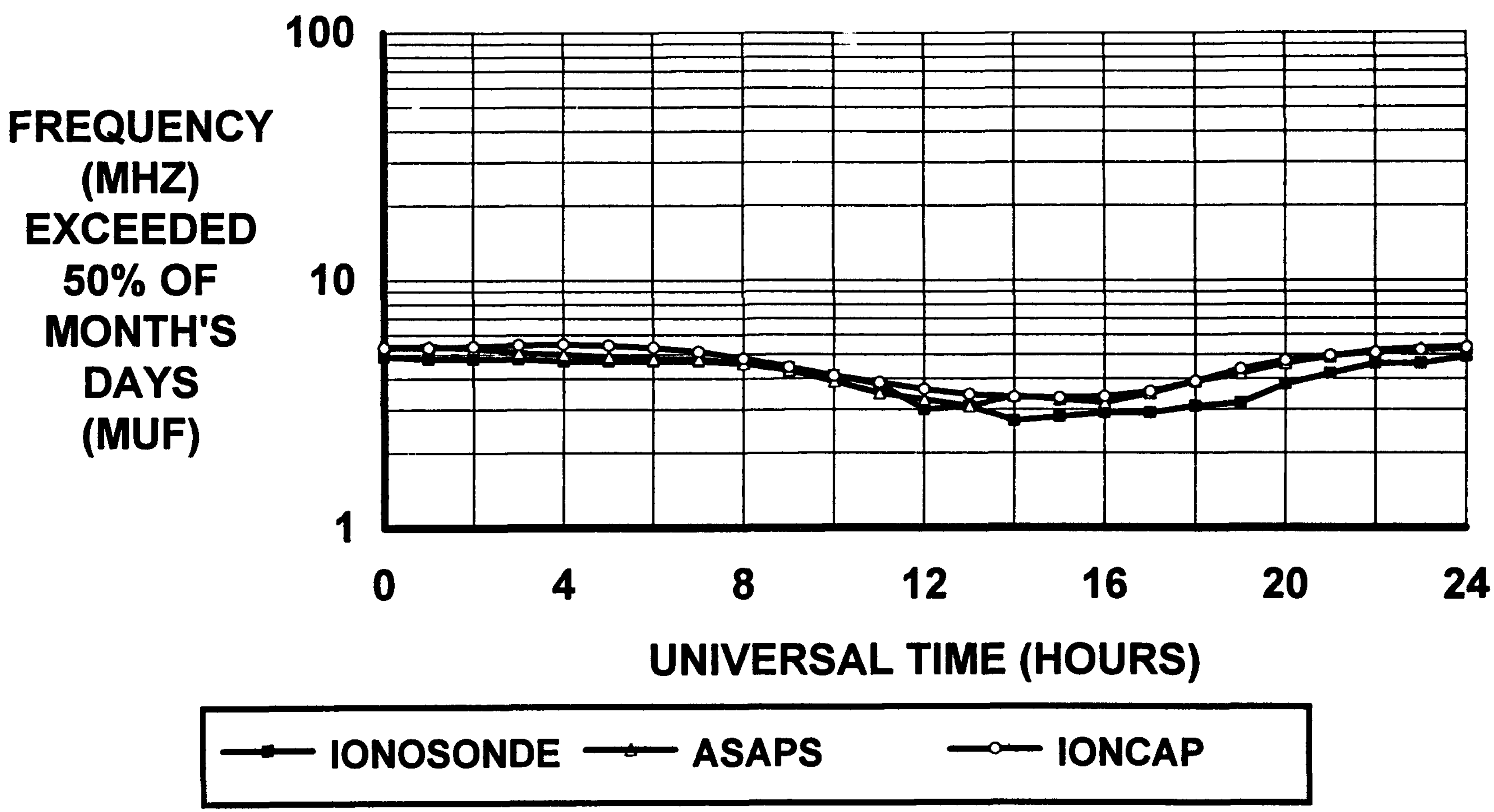


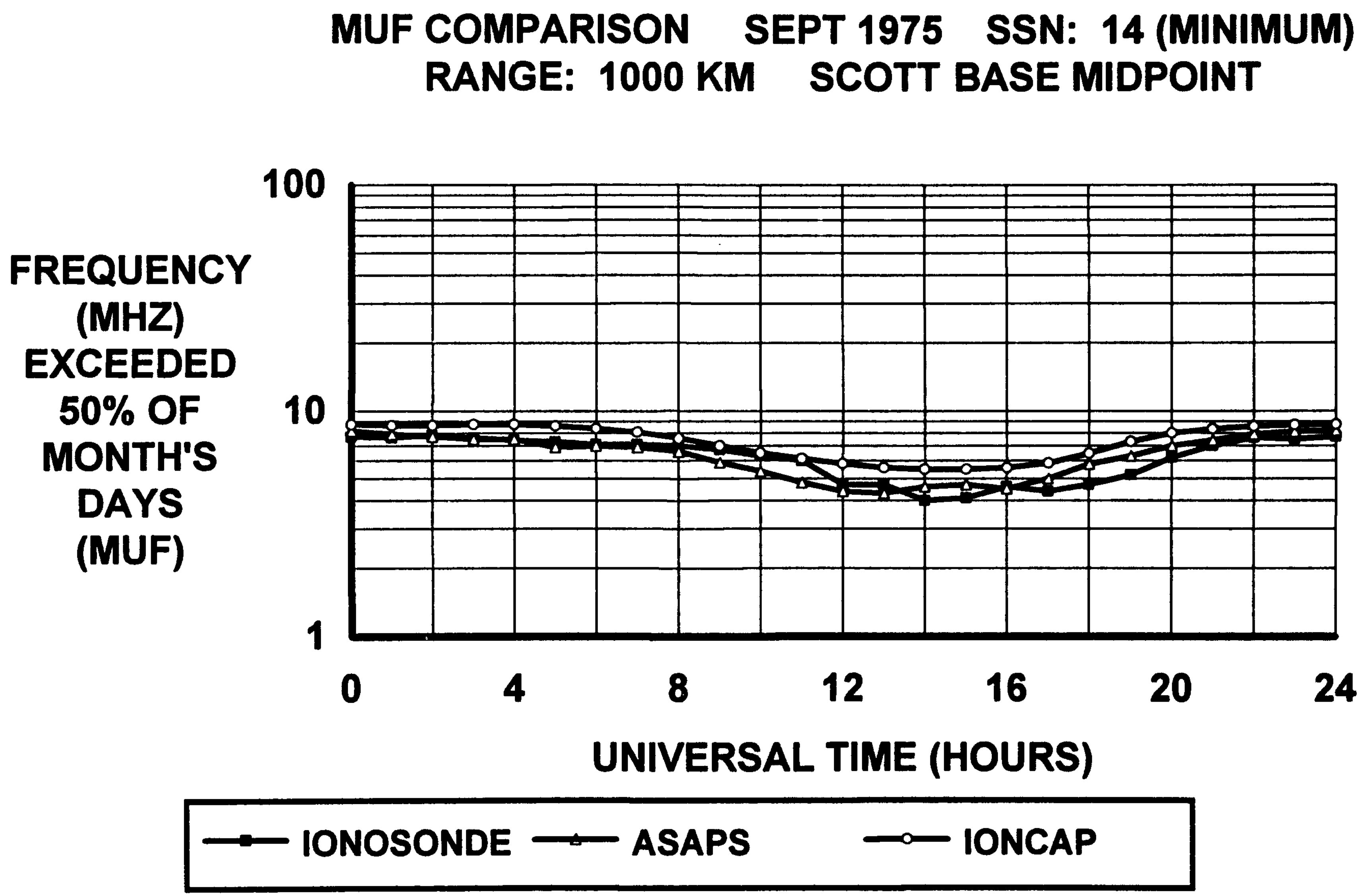
FOT COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

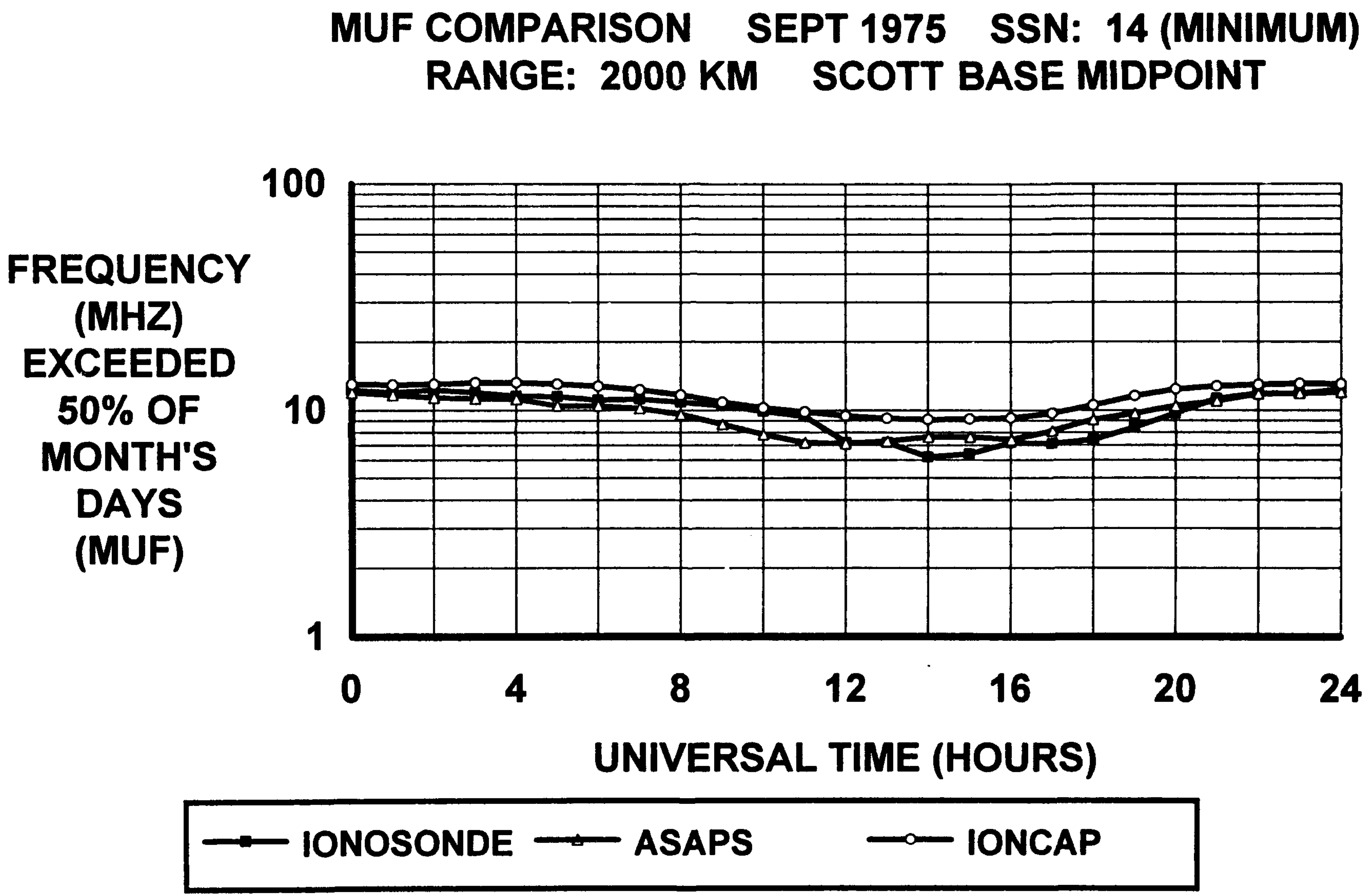
MUF COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT



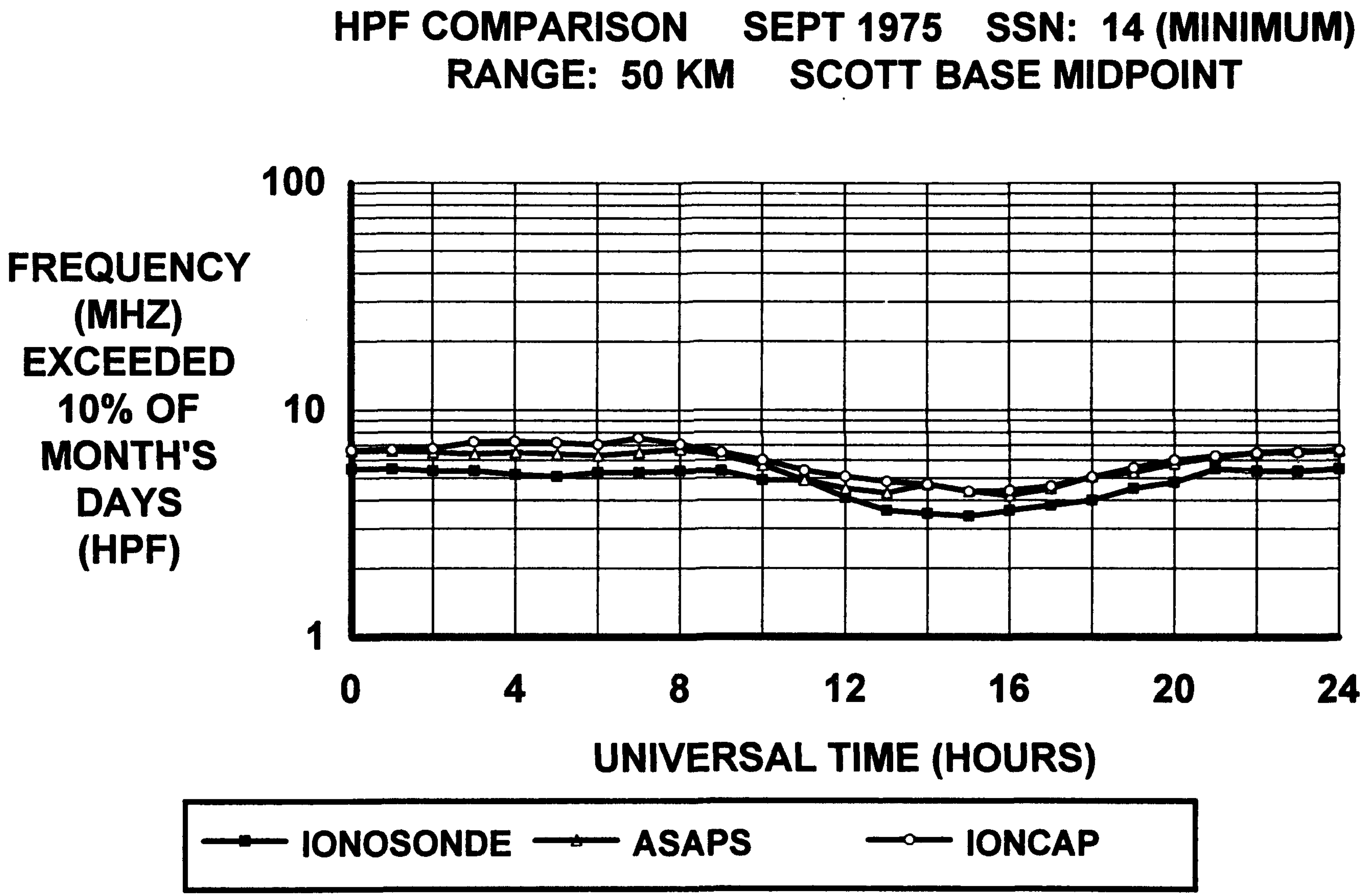
MUF COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT



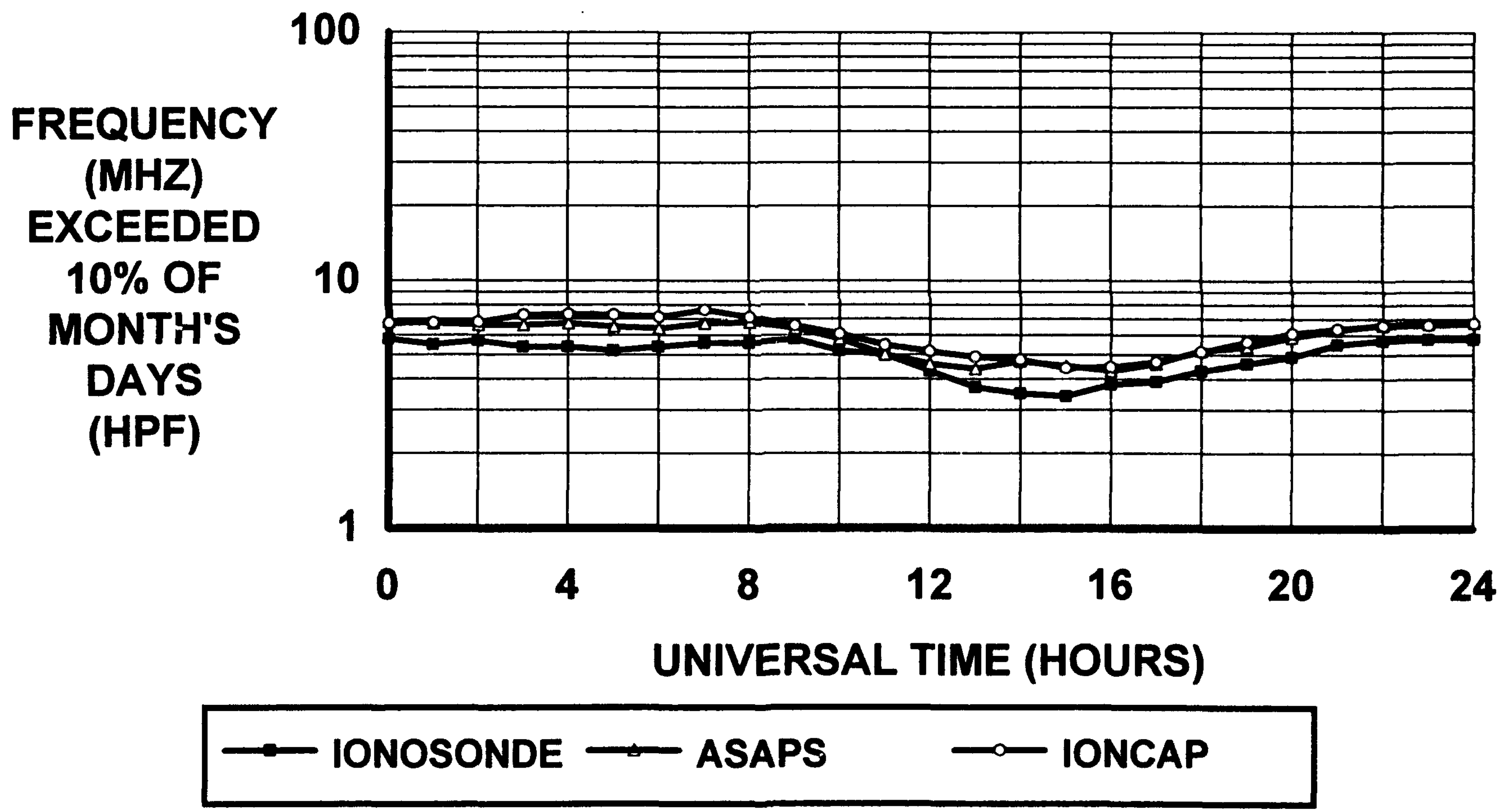

MUF COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

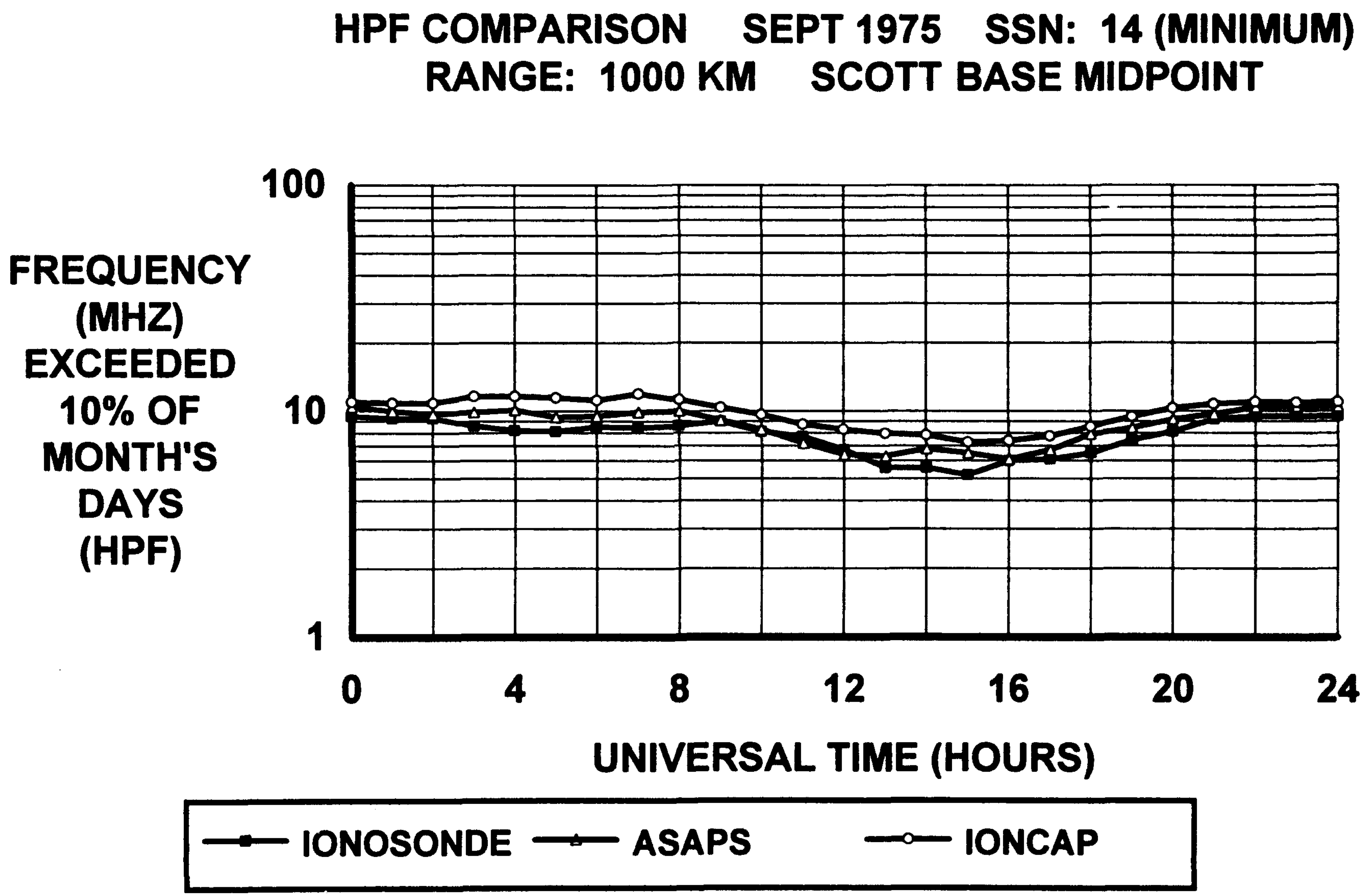


MUF COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


HPF COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

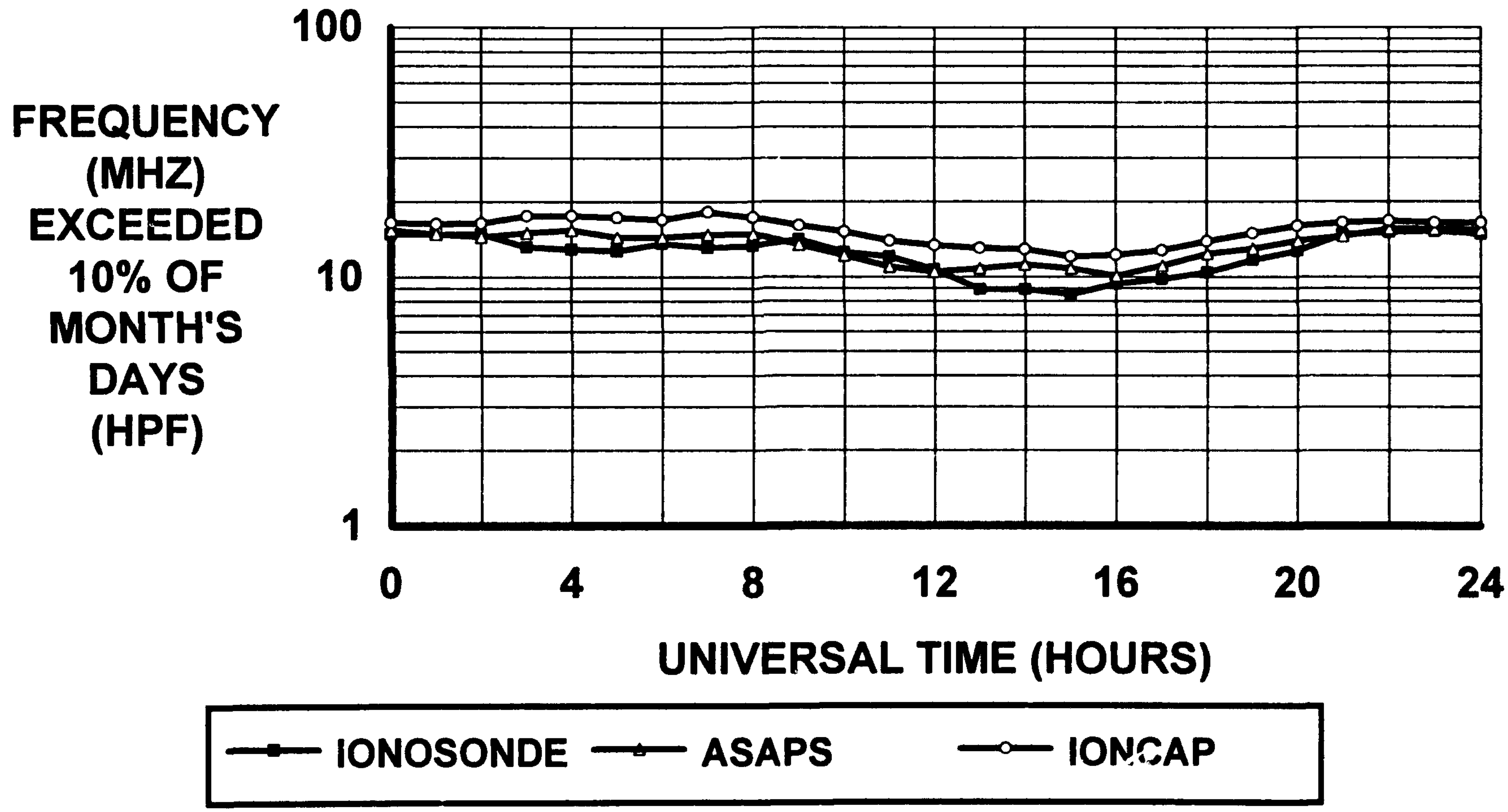
HPF COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT

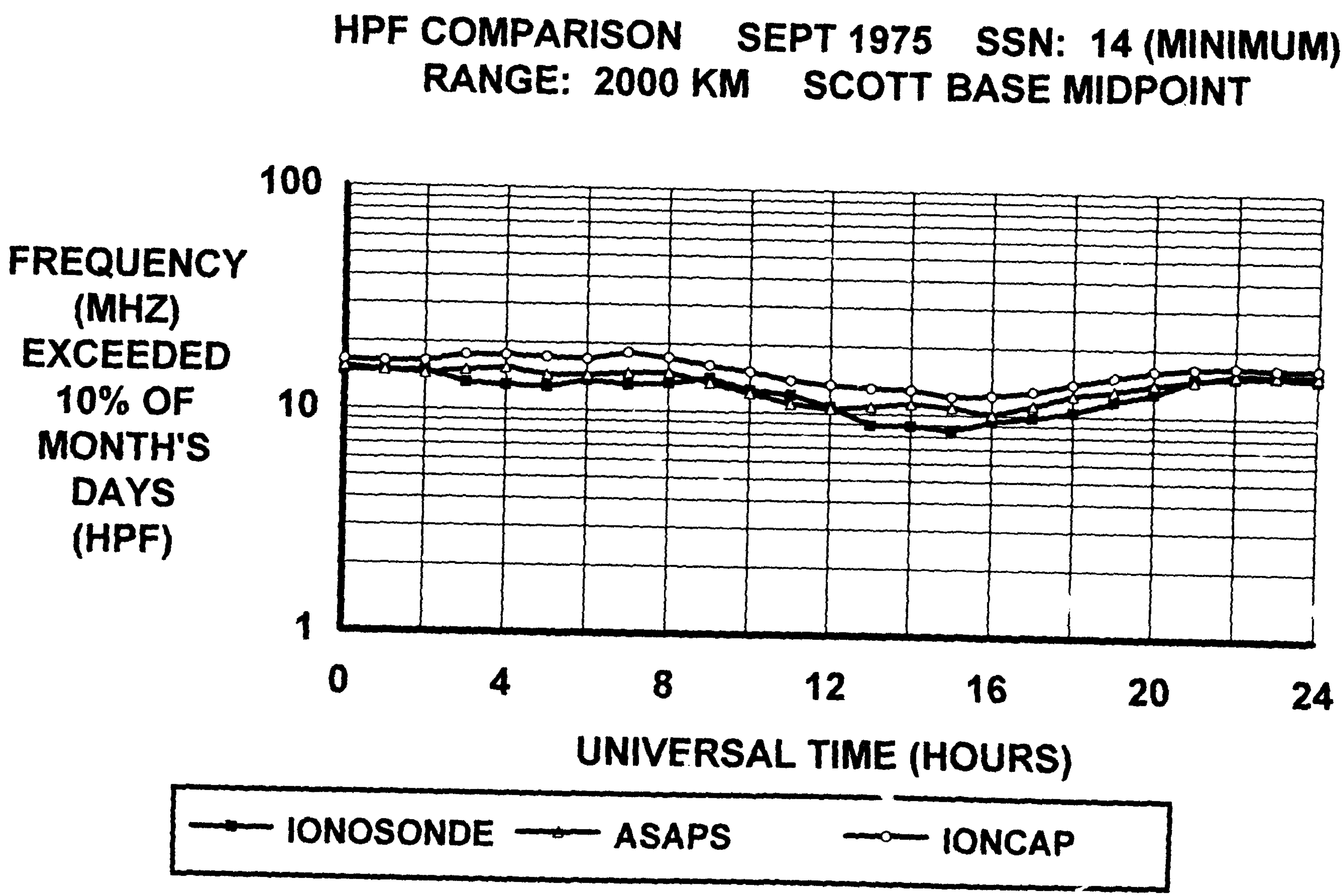


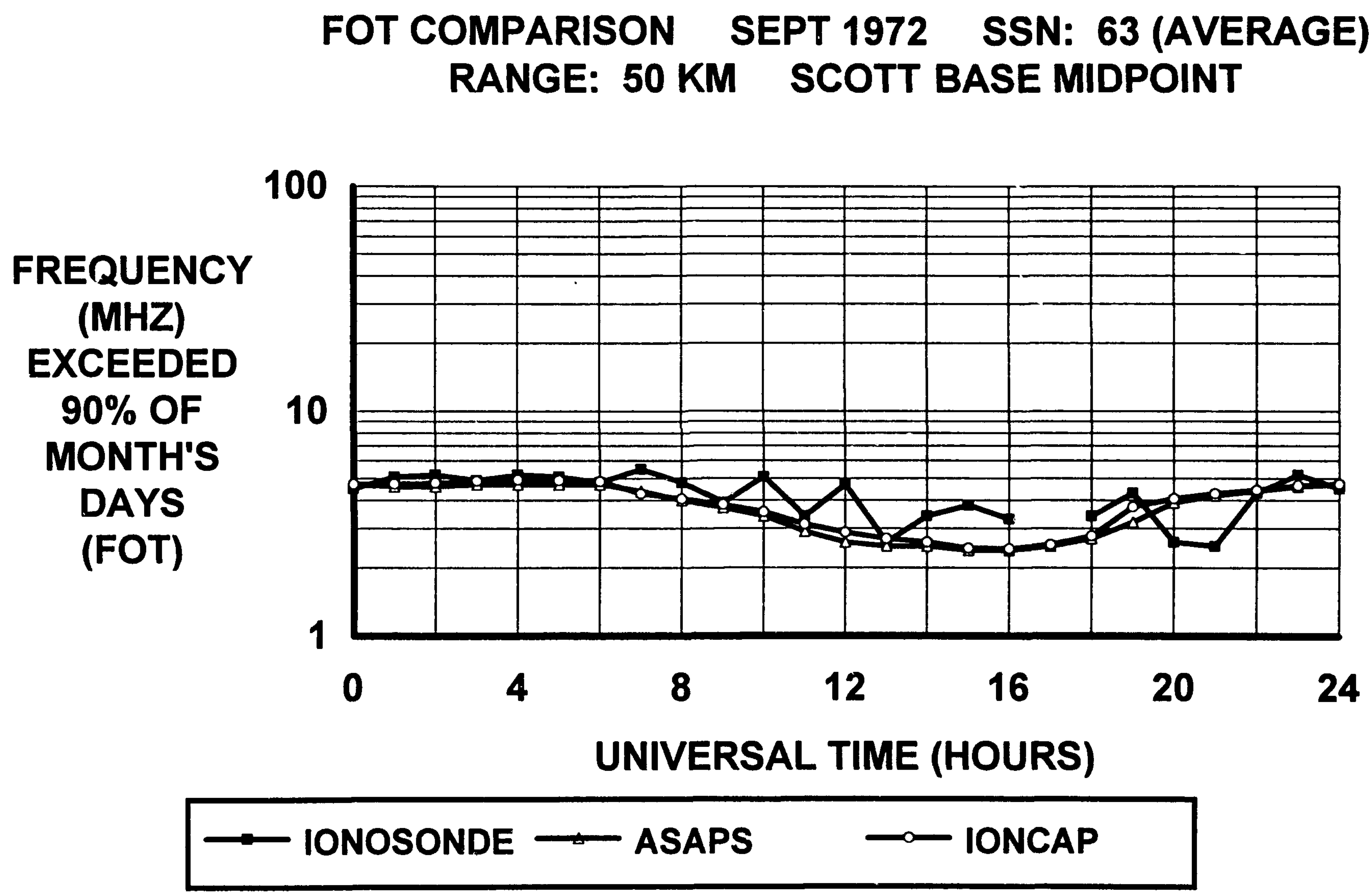


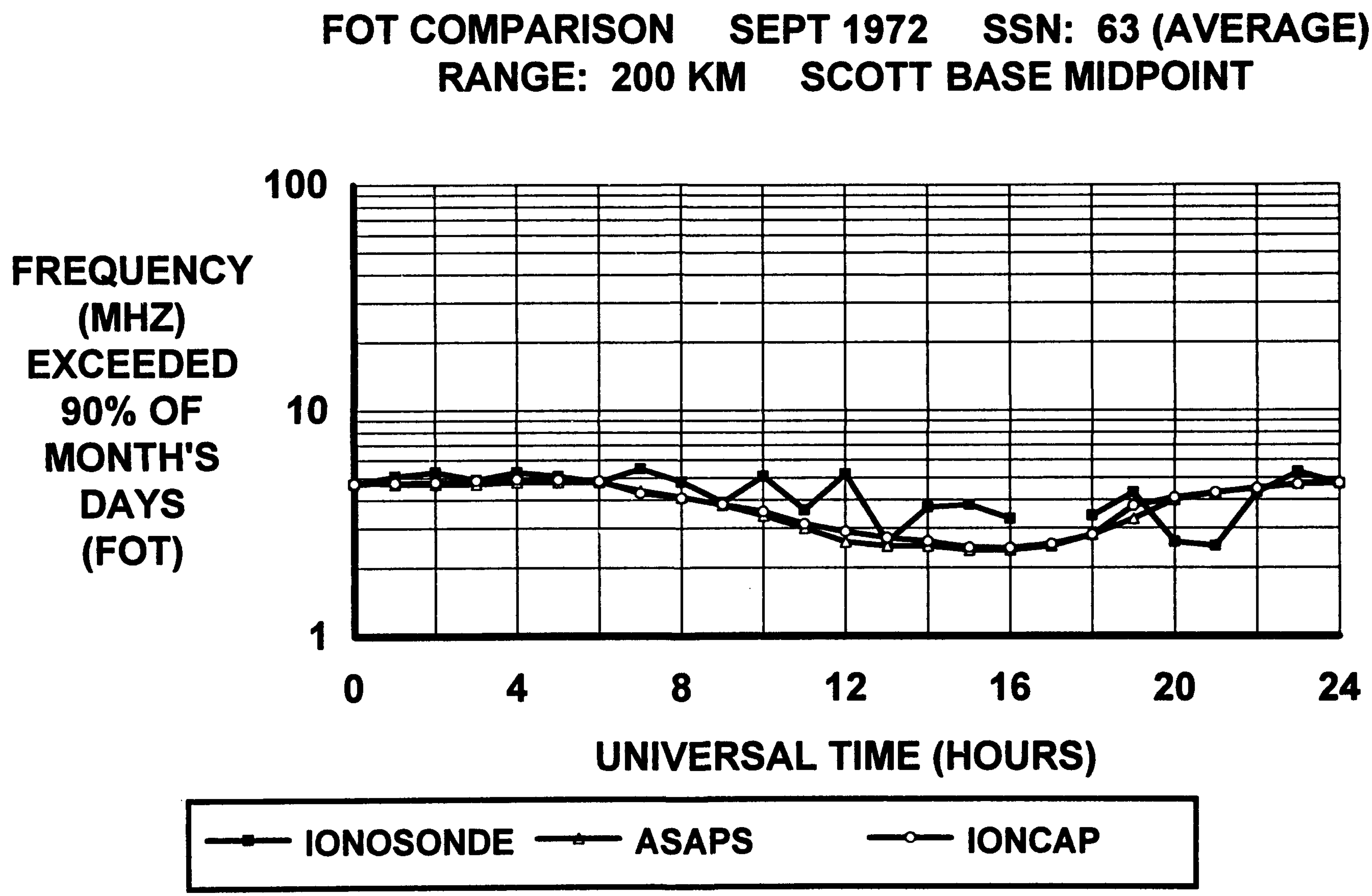
HPF COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

HPF COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT

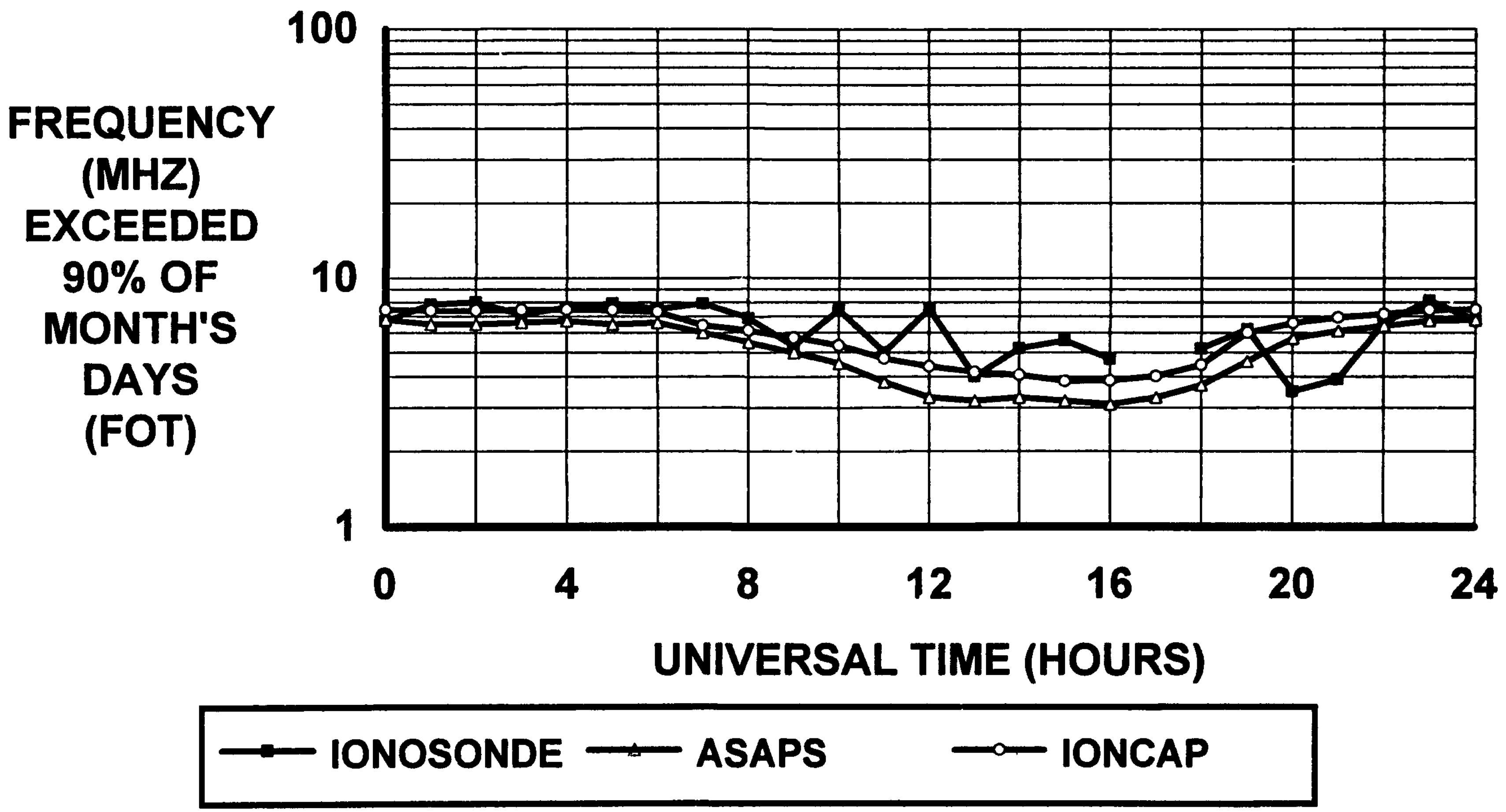


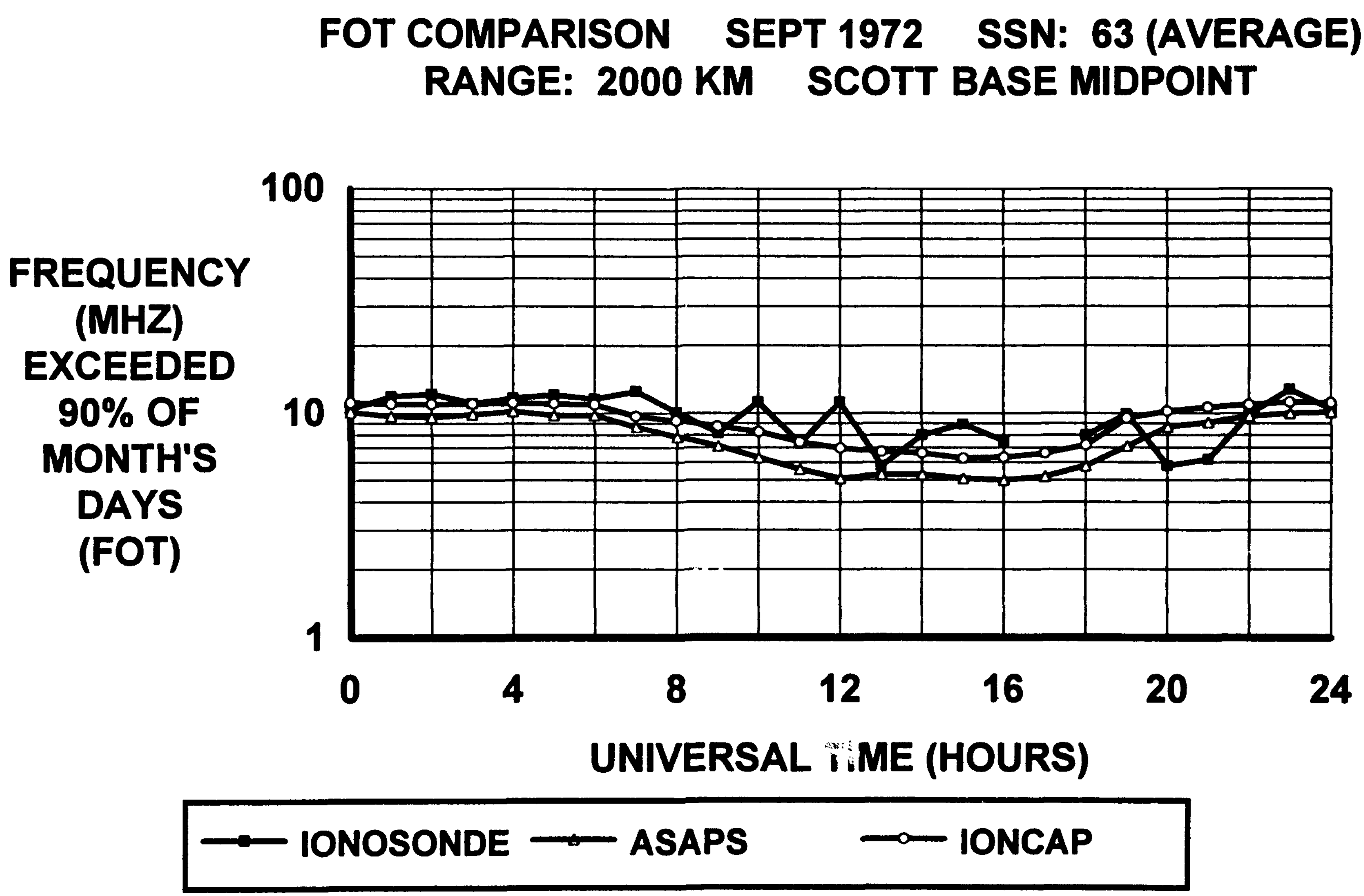

HPF COMPARISON SEPT 1975 SSN: 14 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


FOT COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

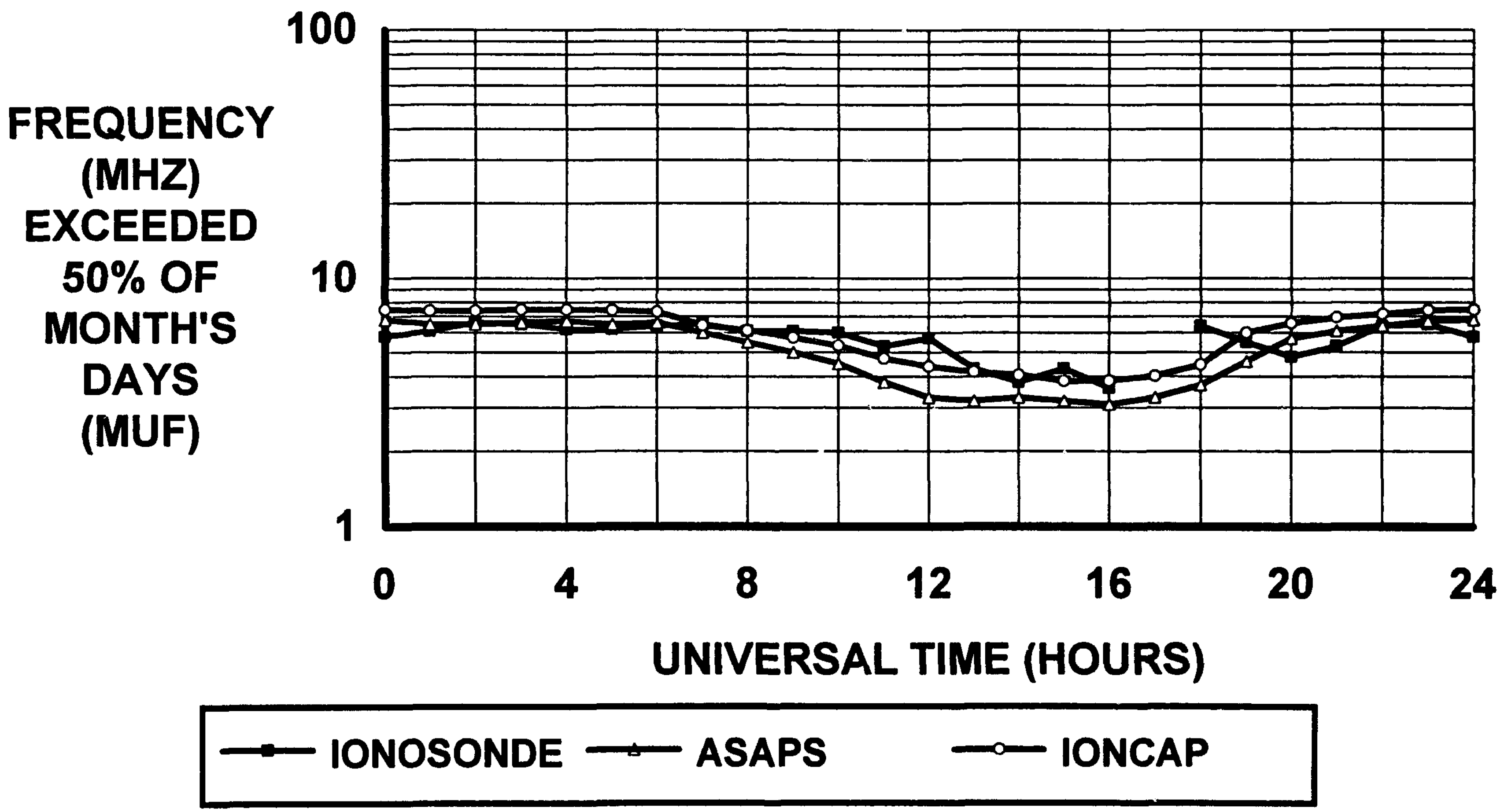

FOT COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

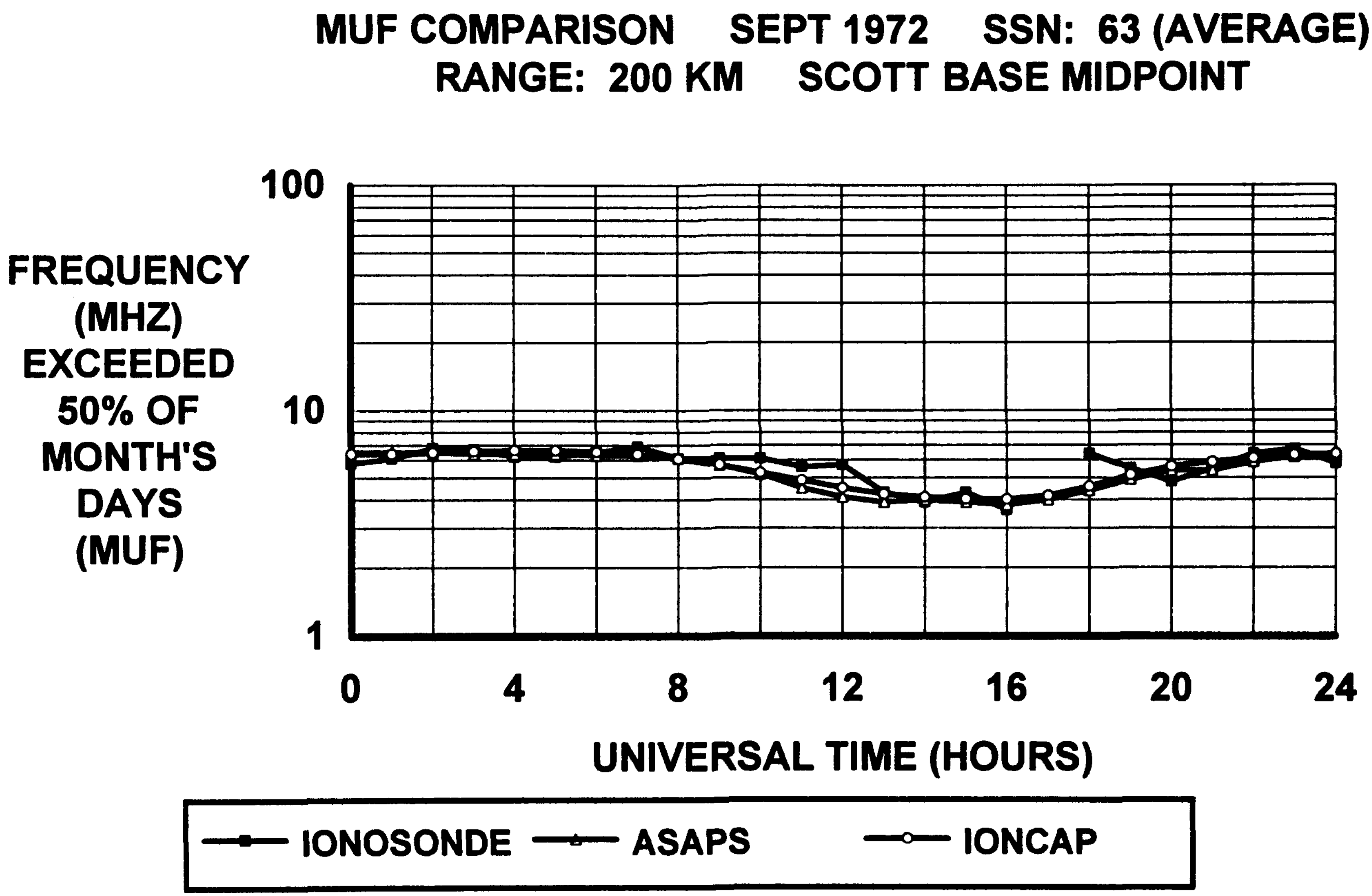
FOT COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 1000 KM SCOTT BASE MIDPOINT



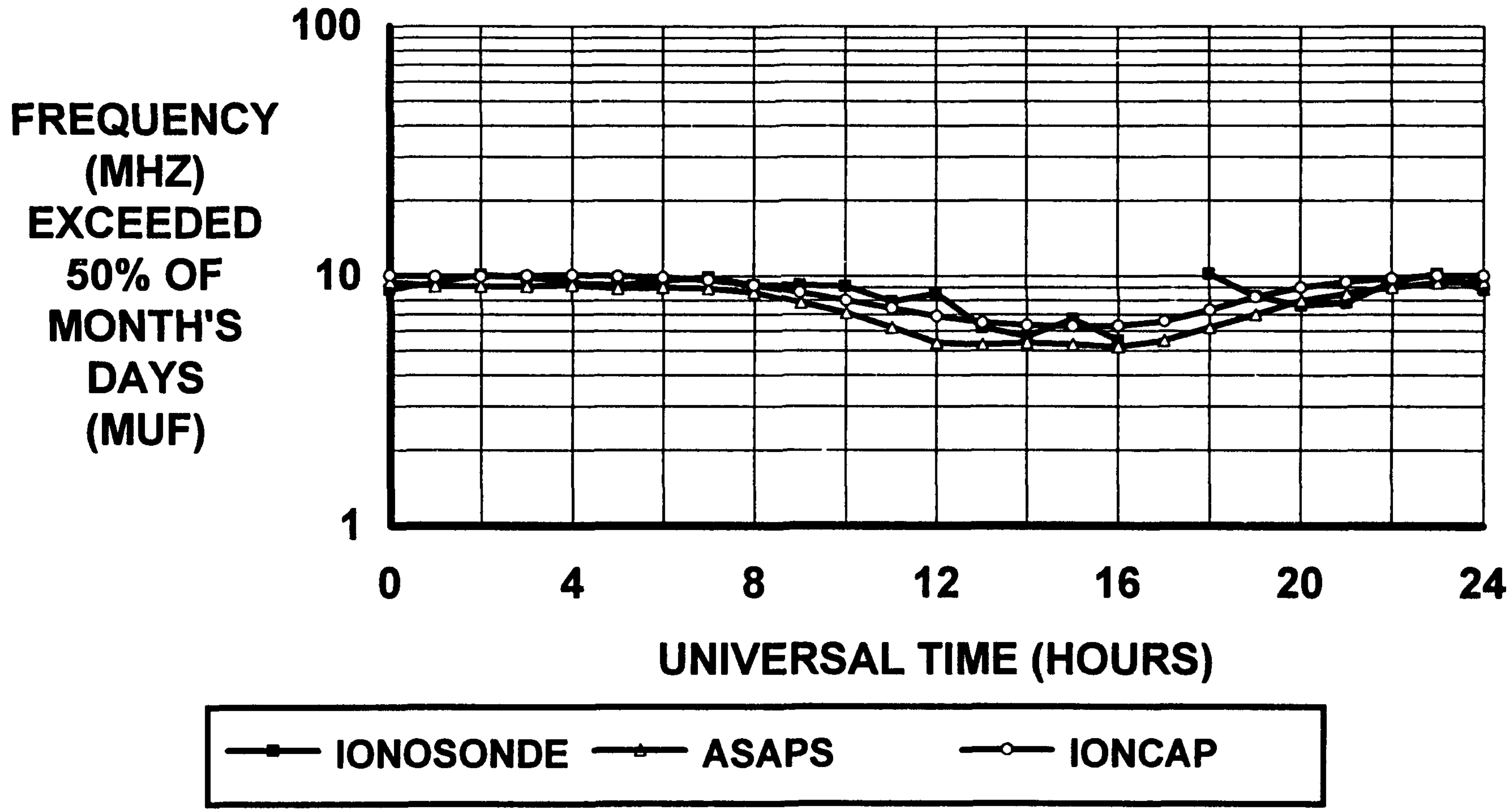

FOT COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

MUF COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT

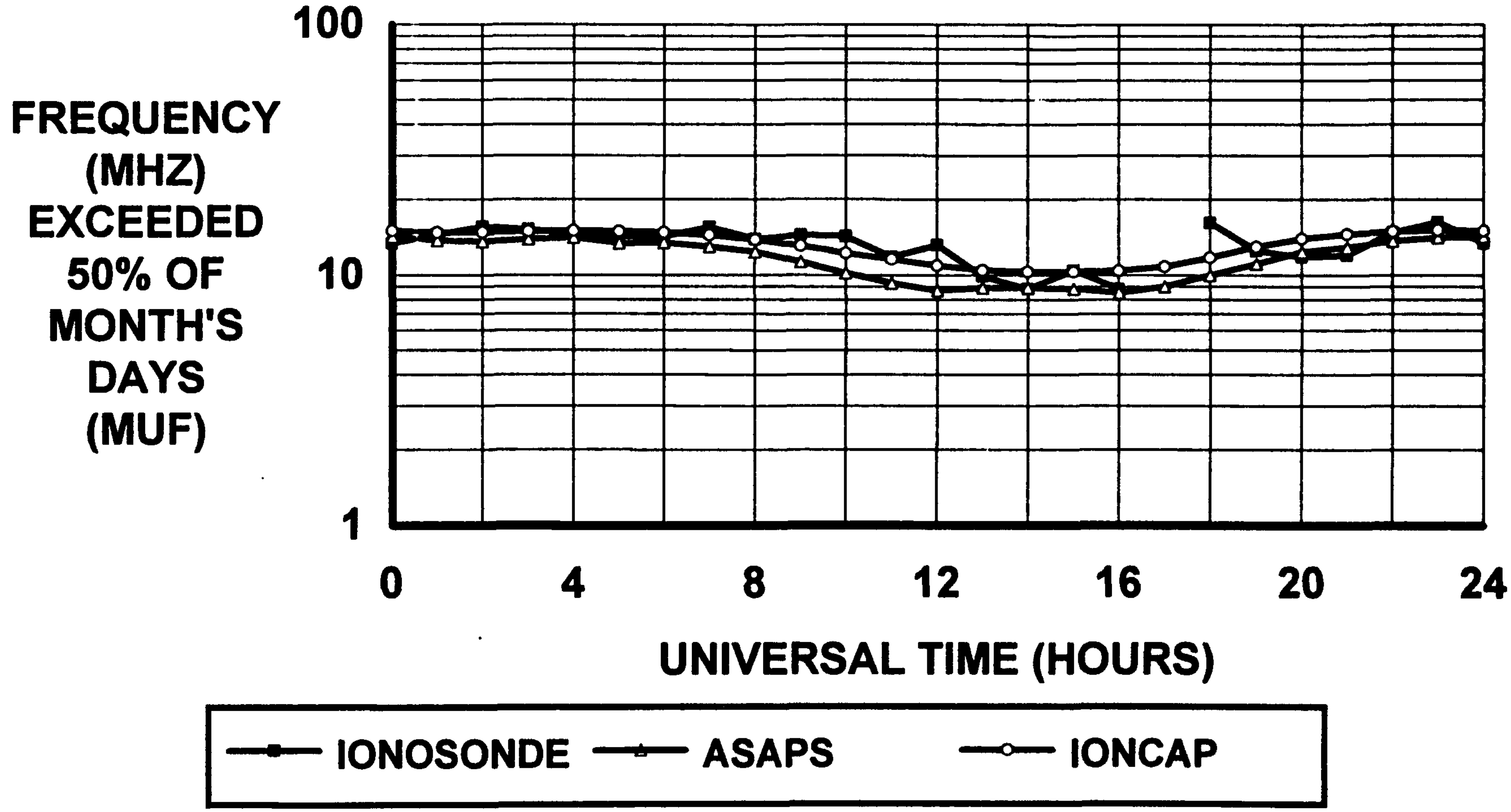



MUF COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

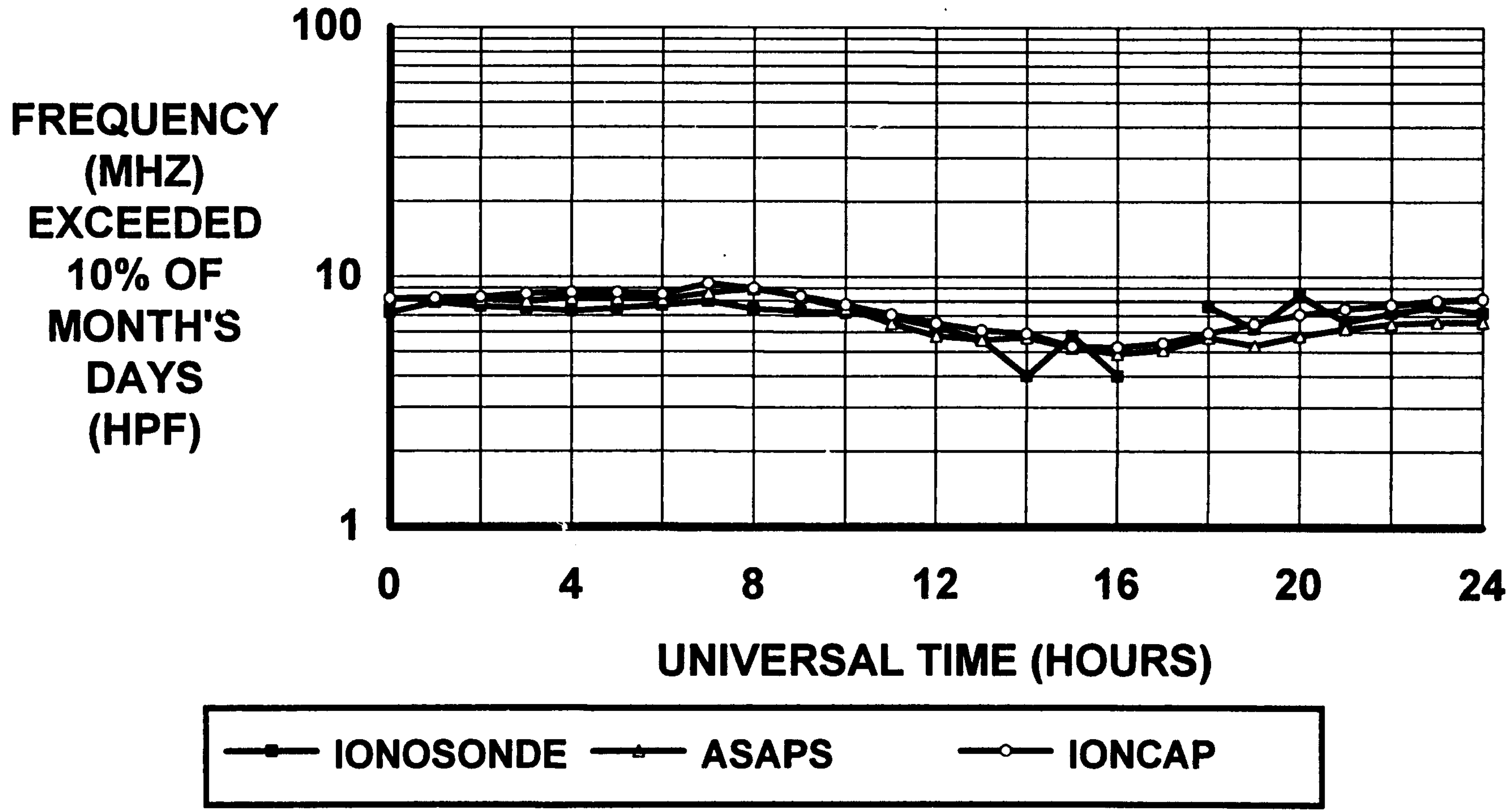
MUF COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 1000 KM SCOTT BASE MIDPOINT

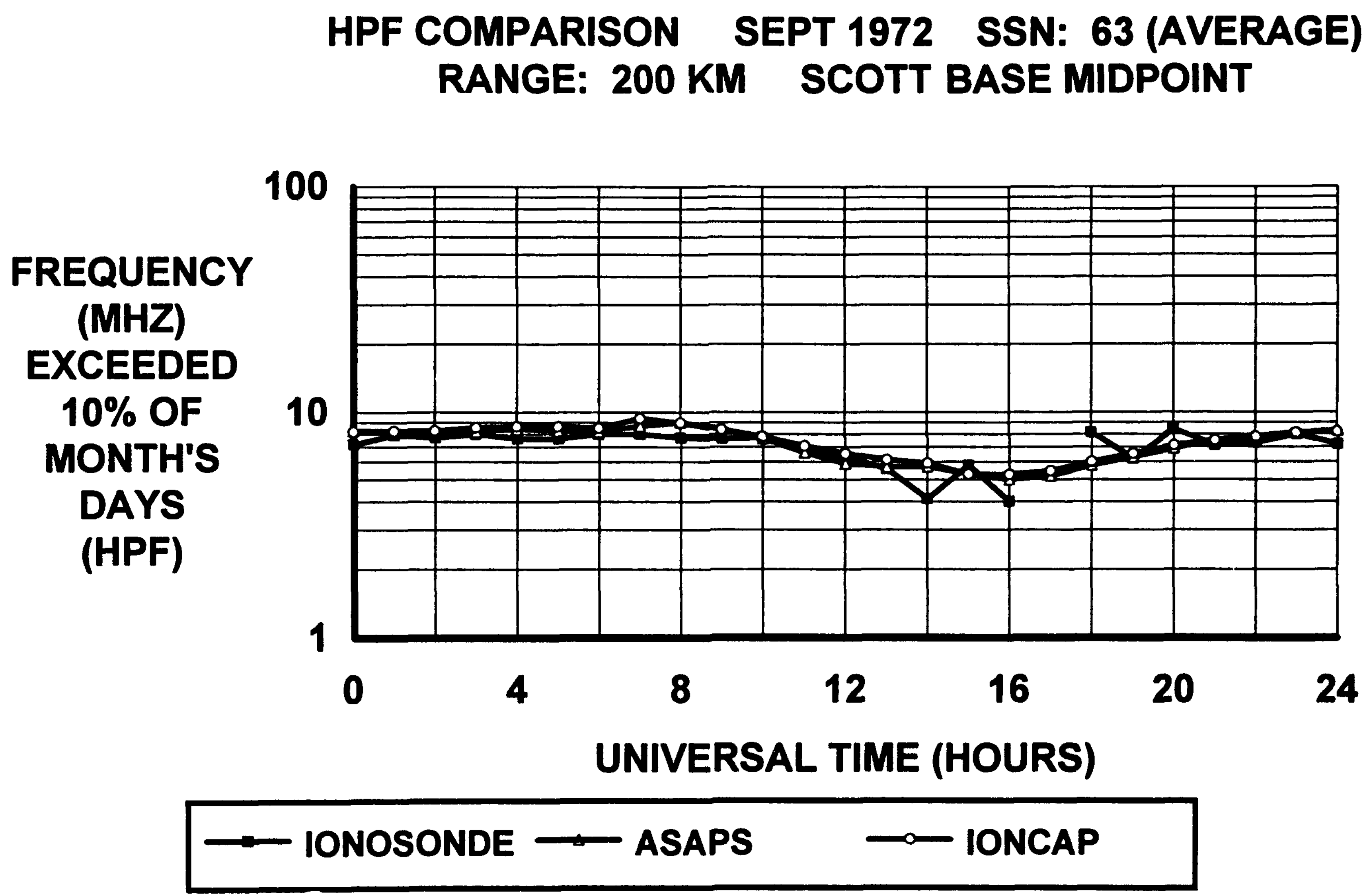


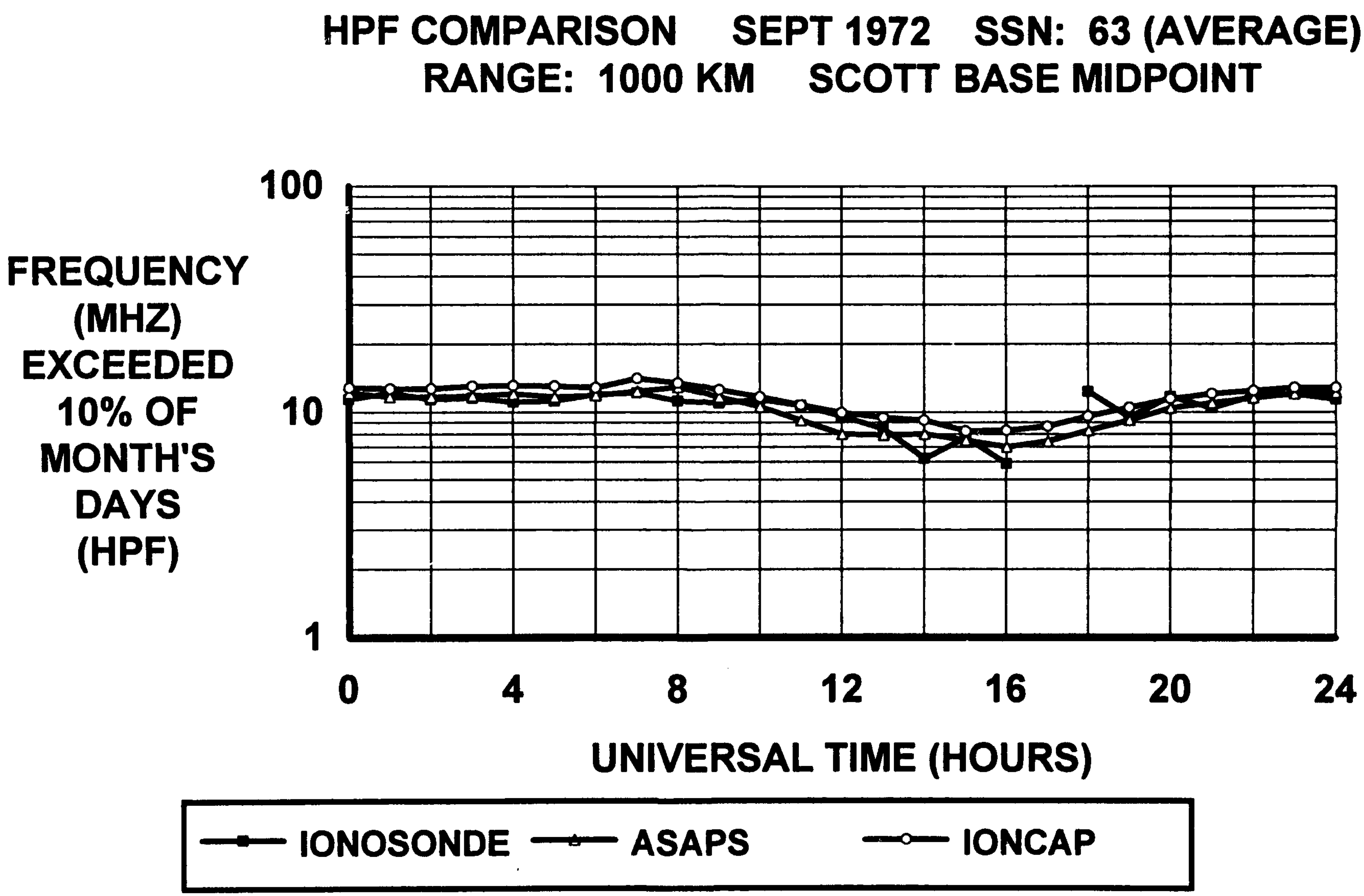
MUF COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT



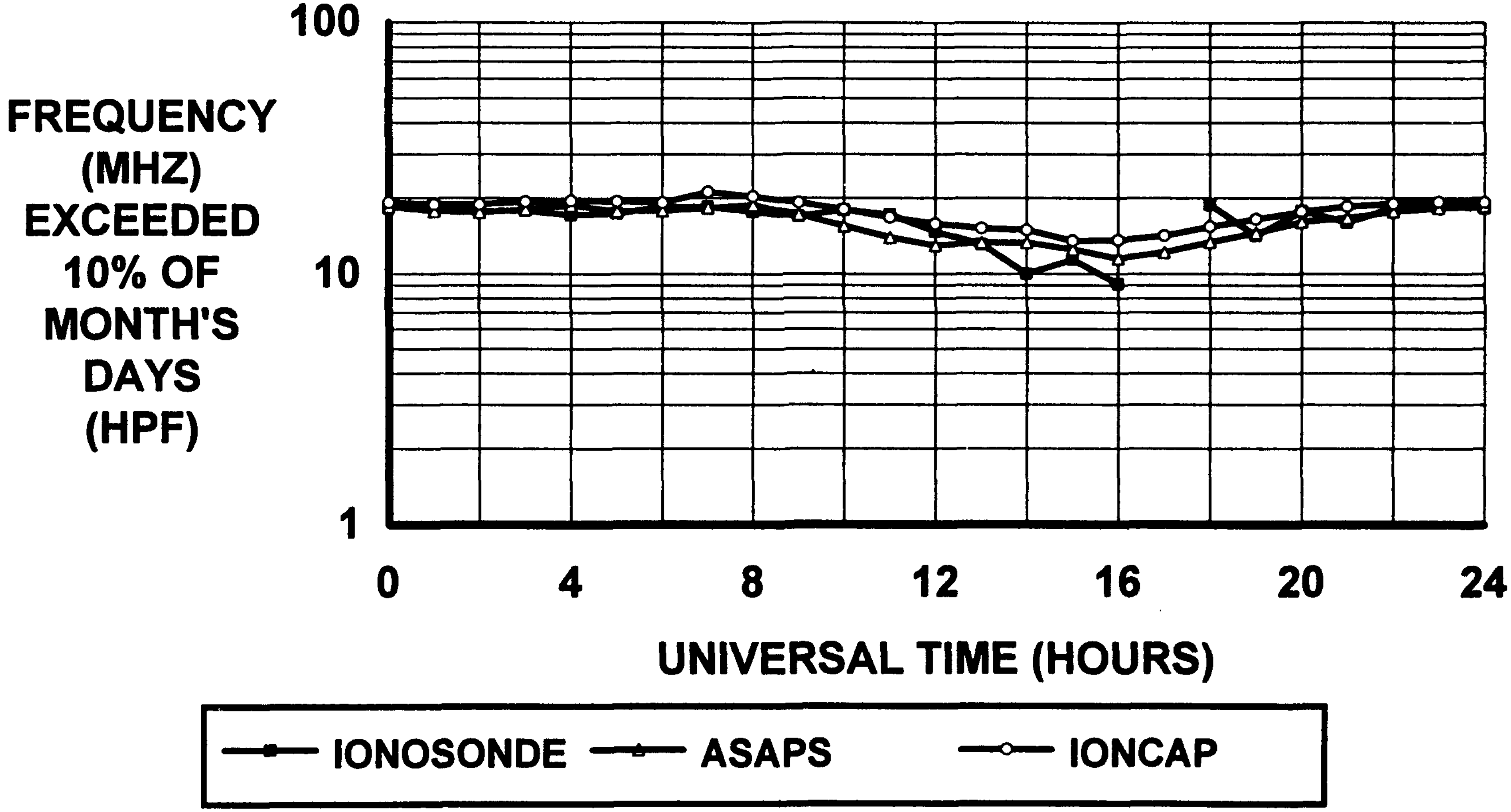
HPF COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT



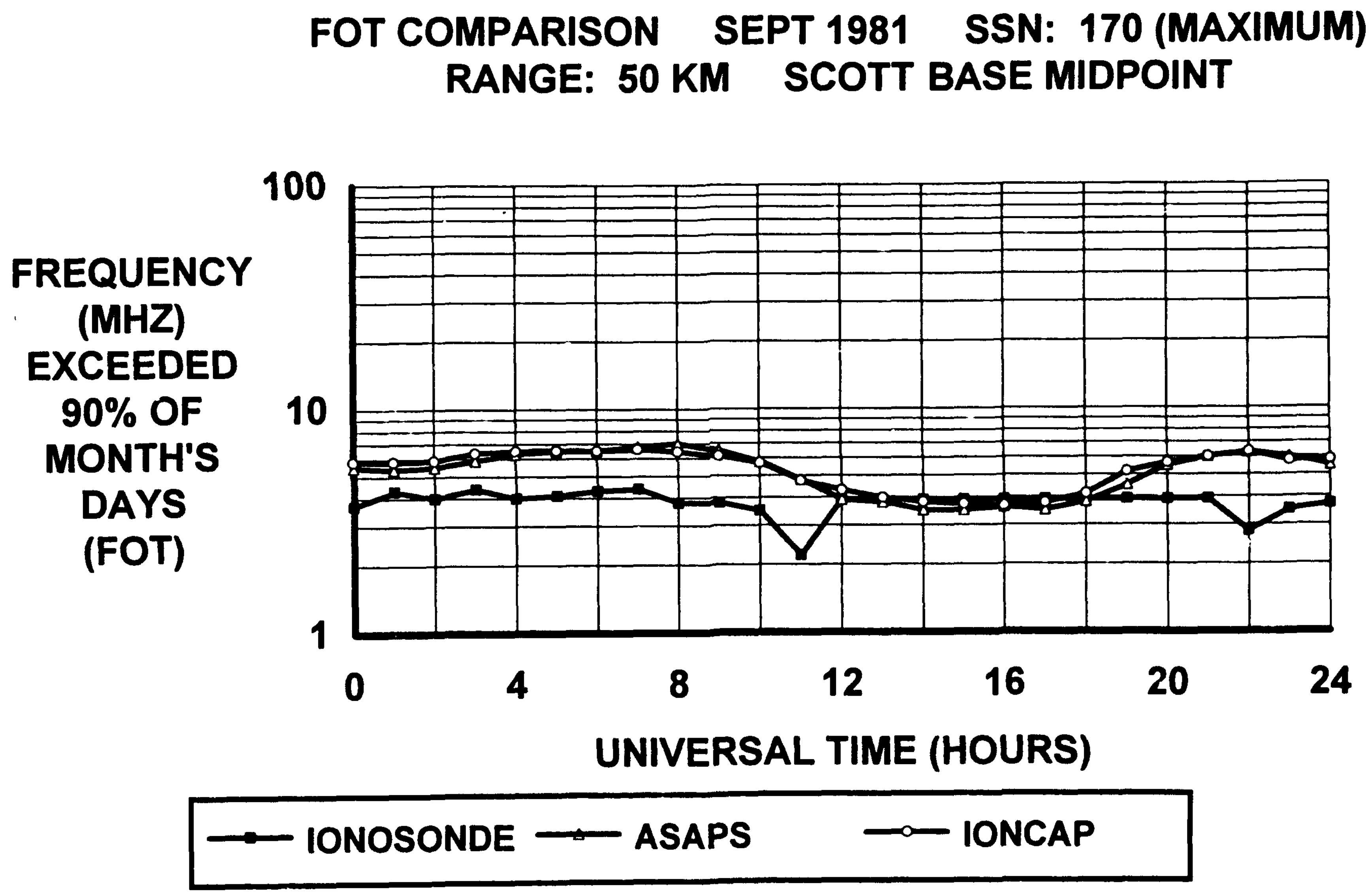

HPF COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

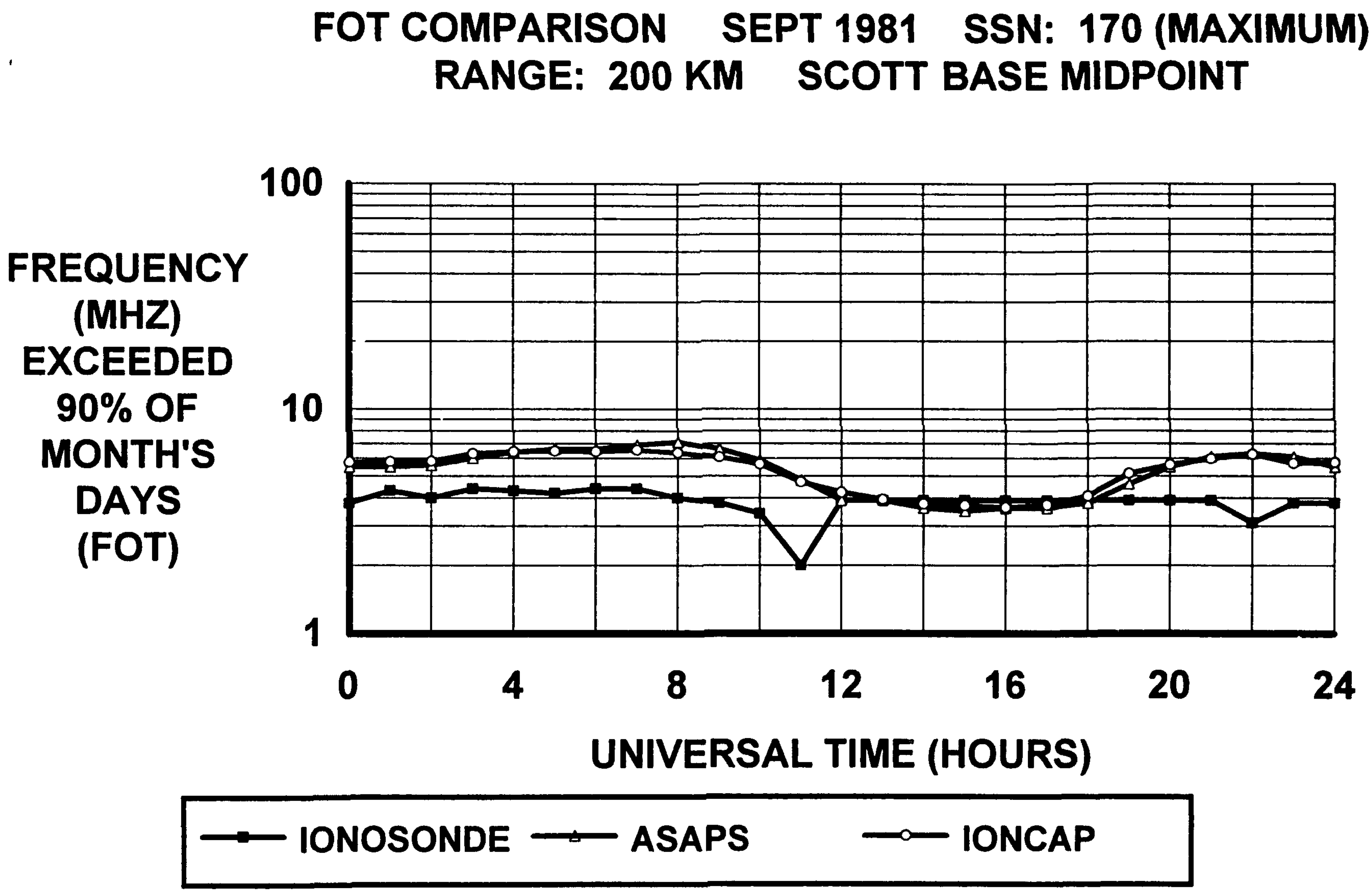

HPF COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

HPF COMPARISON SEPT 1972 SSN: 63 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT

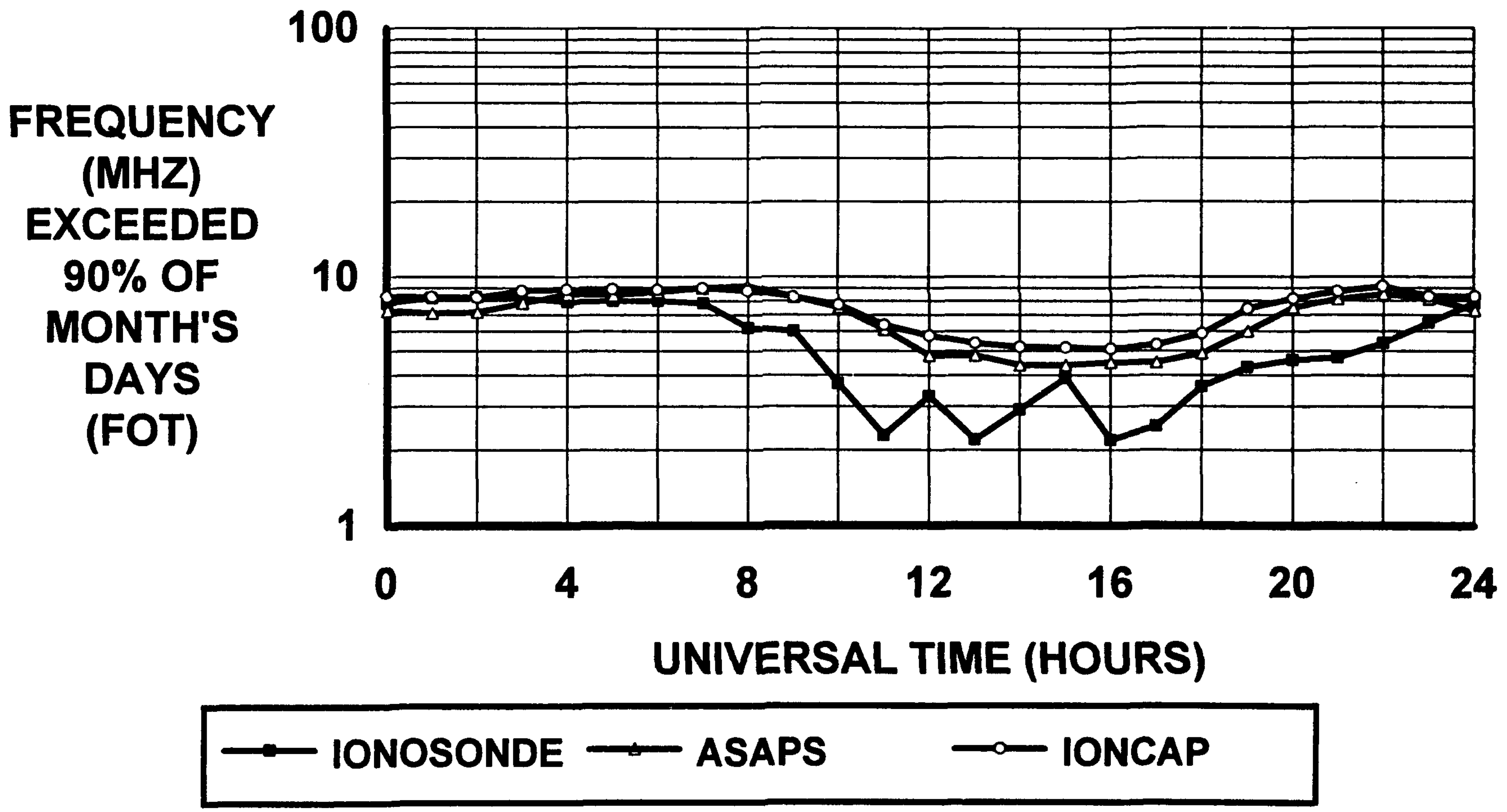


		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	[redacted]	[redacted]	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	[redacted]	[redacted]	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	[redacted]	[redacted]	200 / 1979	D-157 to D-160

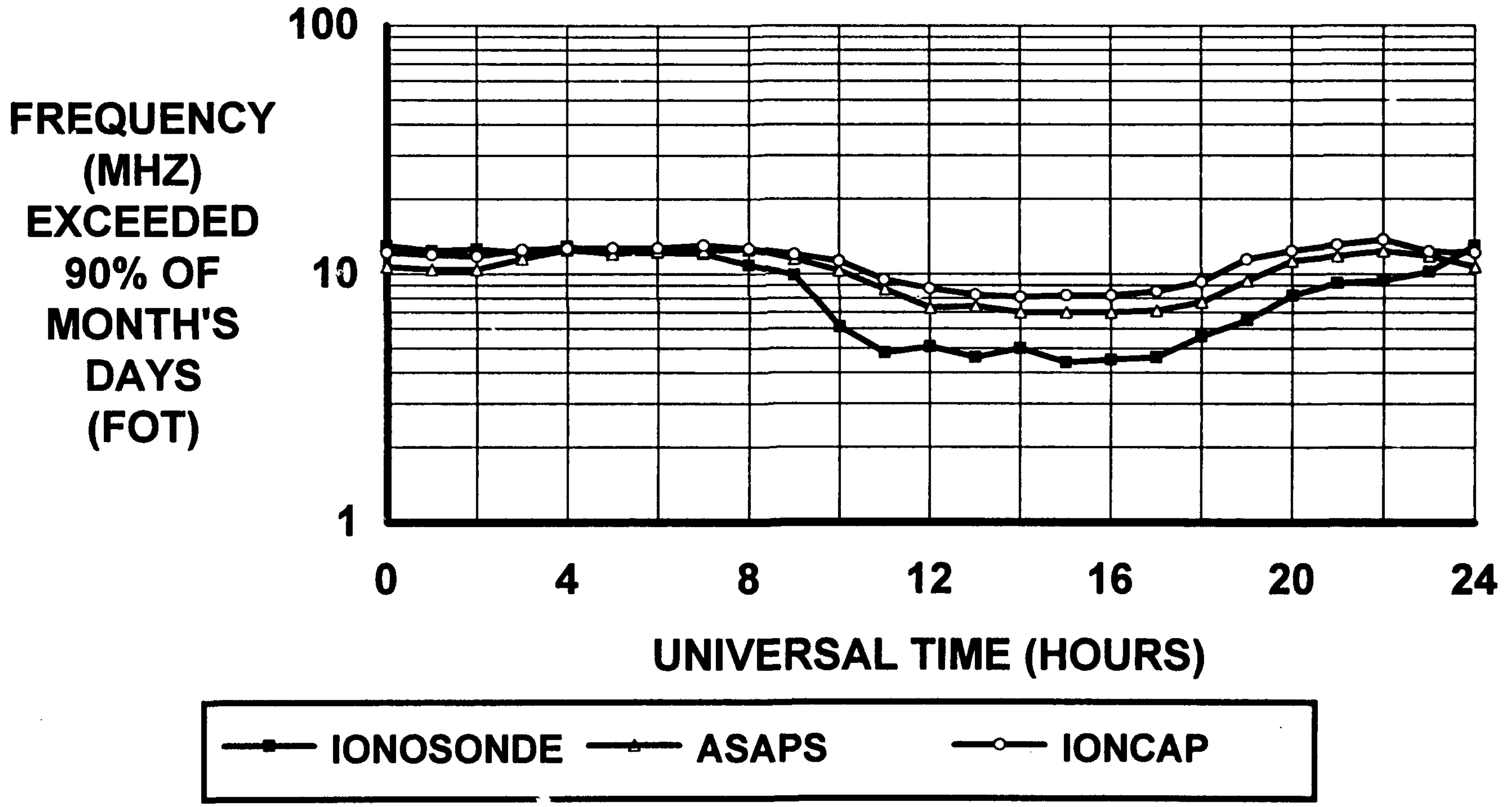

FOT COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


FOT COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

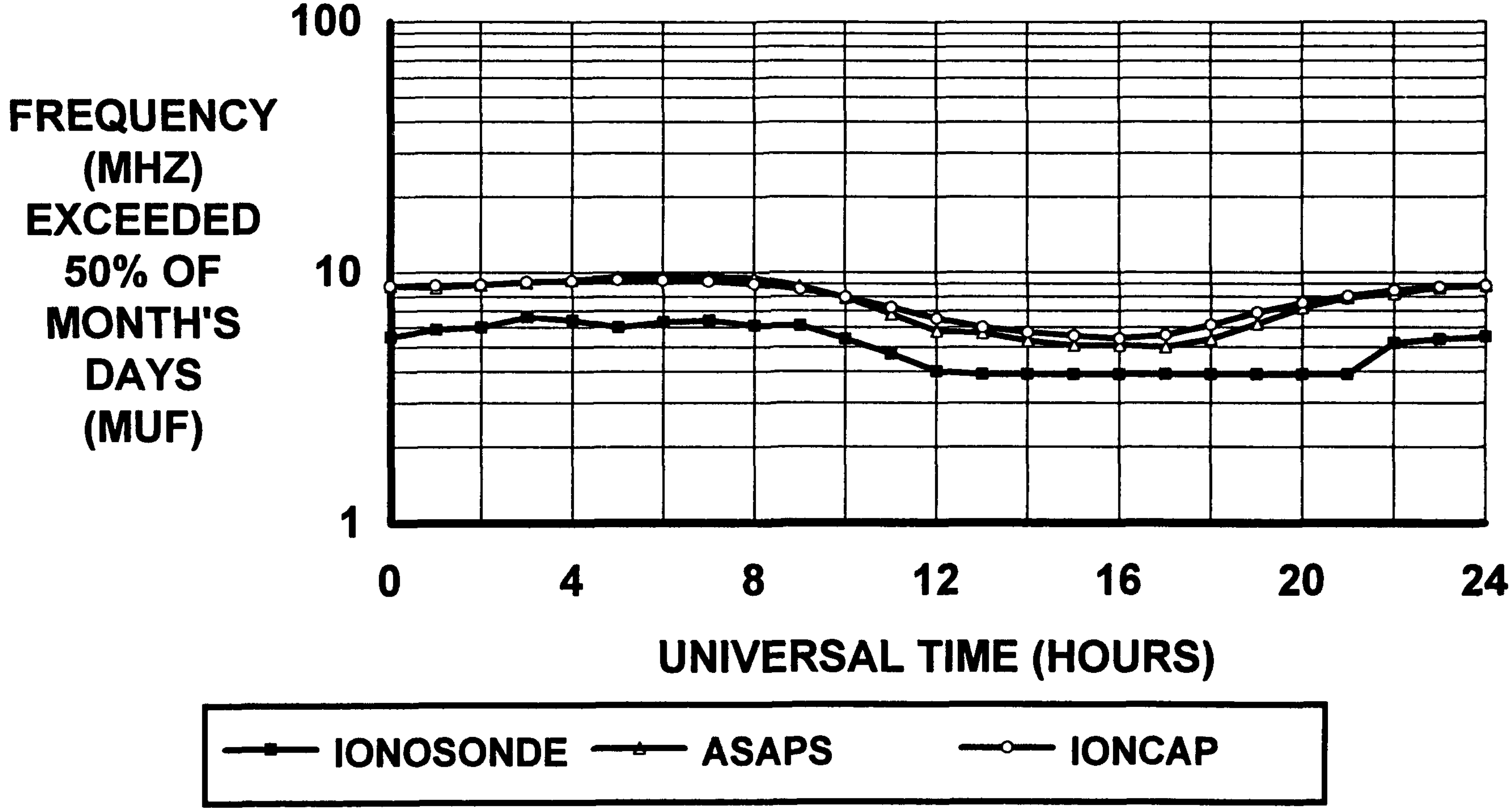
FOT COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT

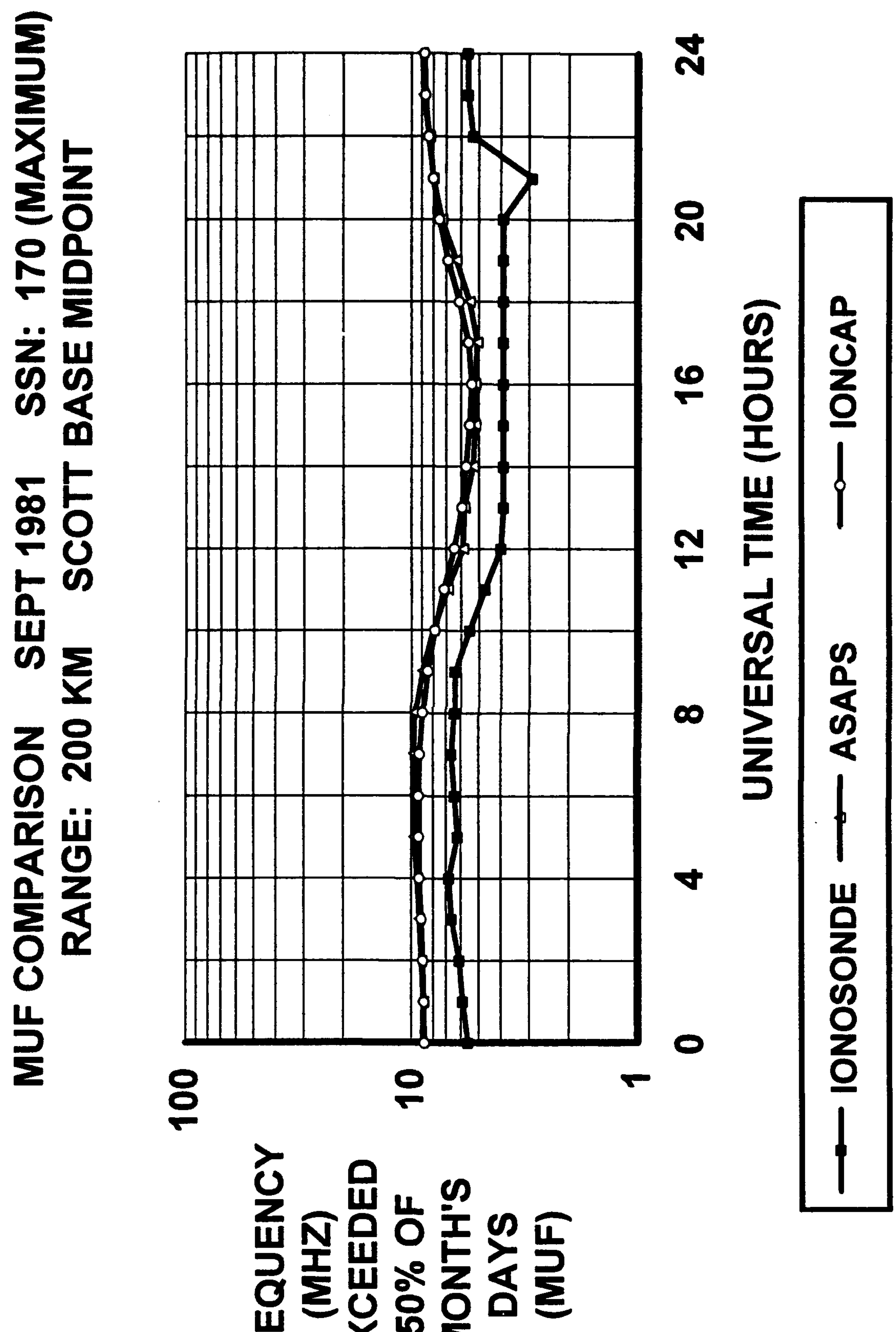


FOT COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT

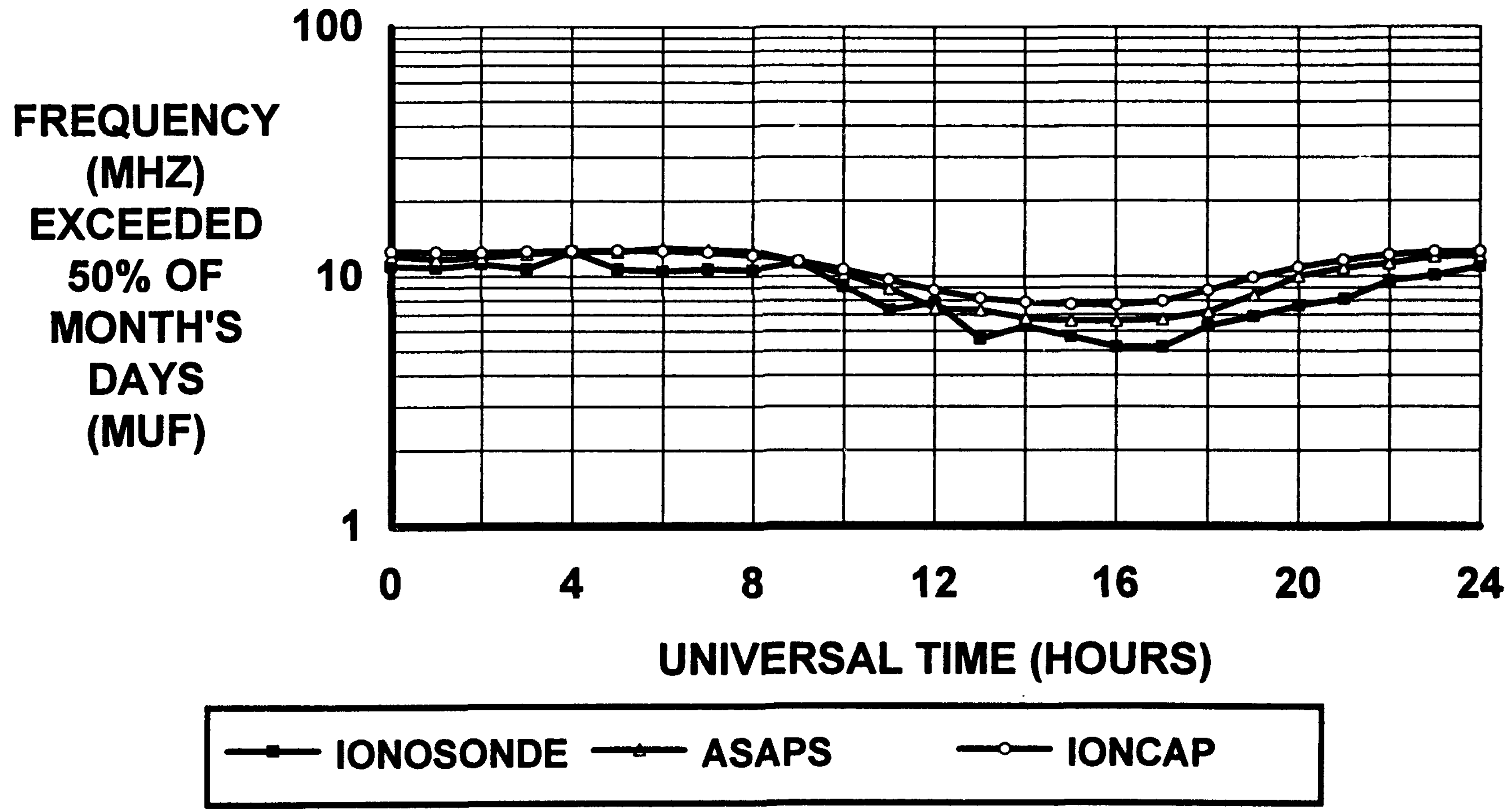


MUF COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT

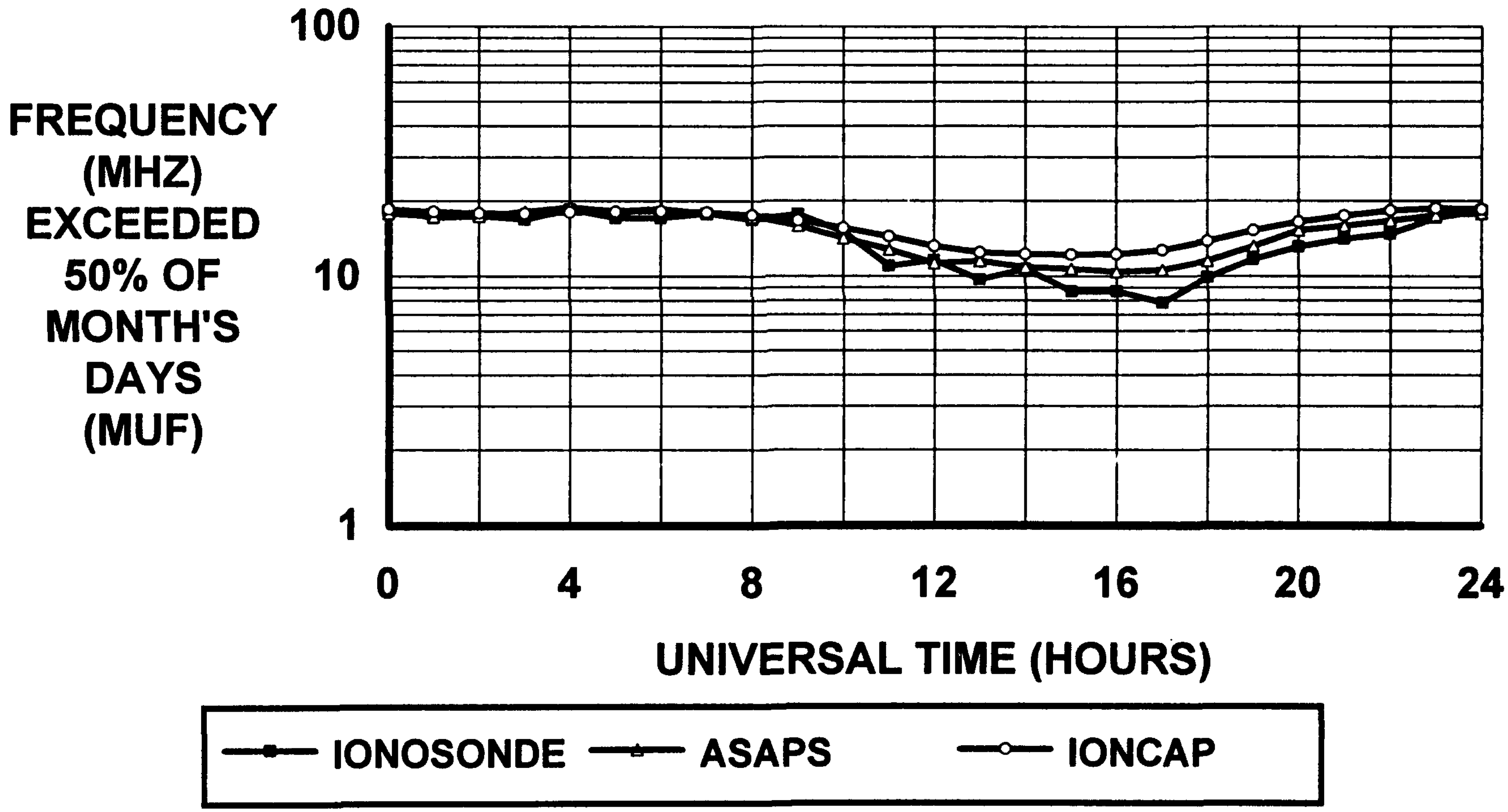


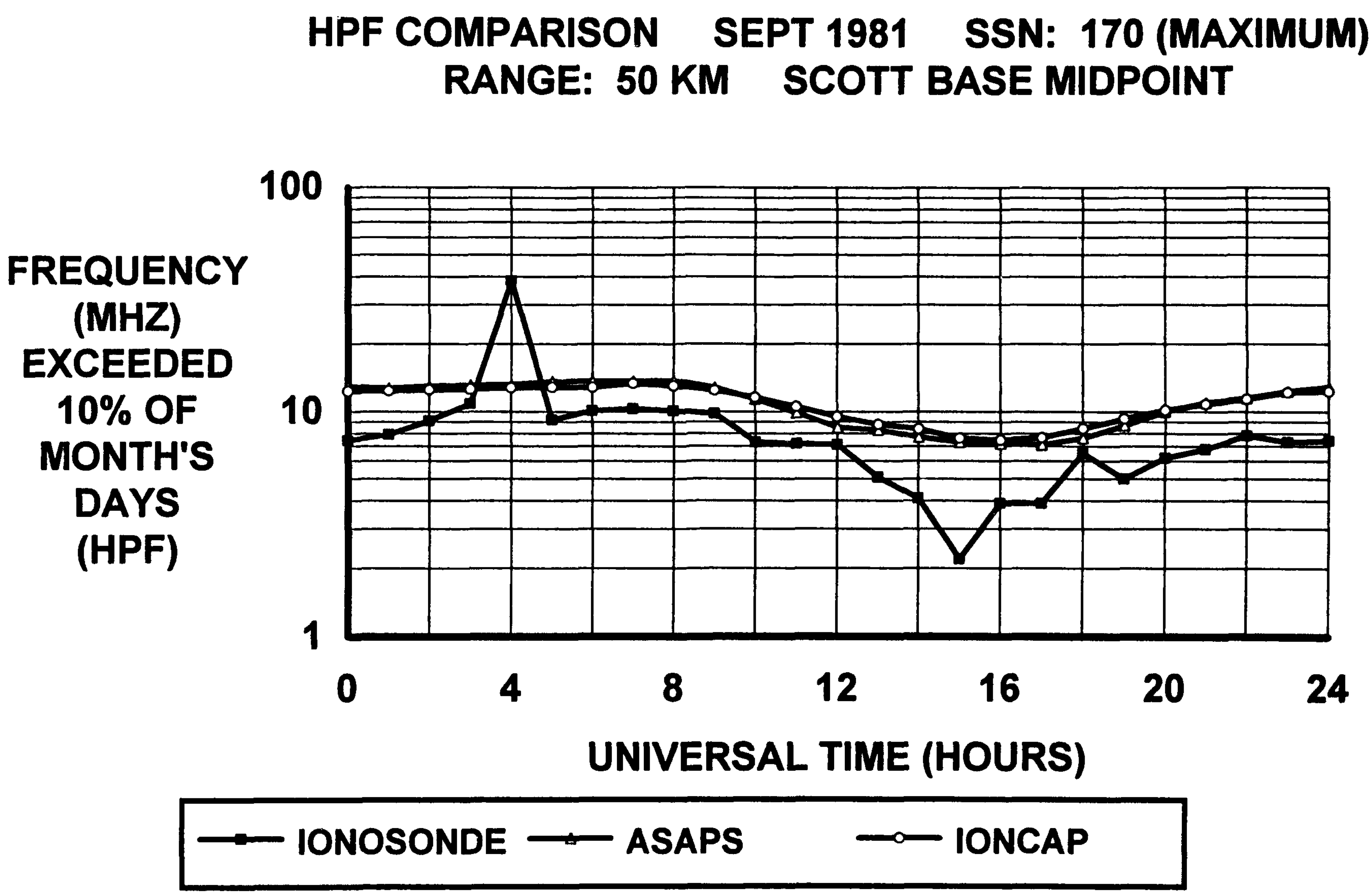

MUF COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

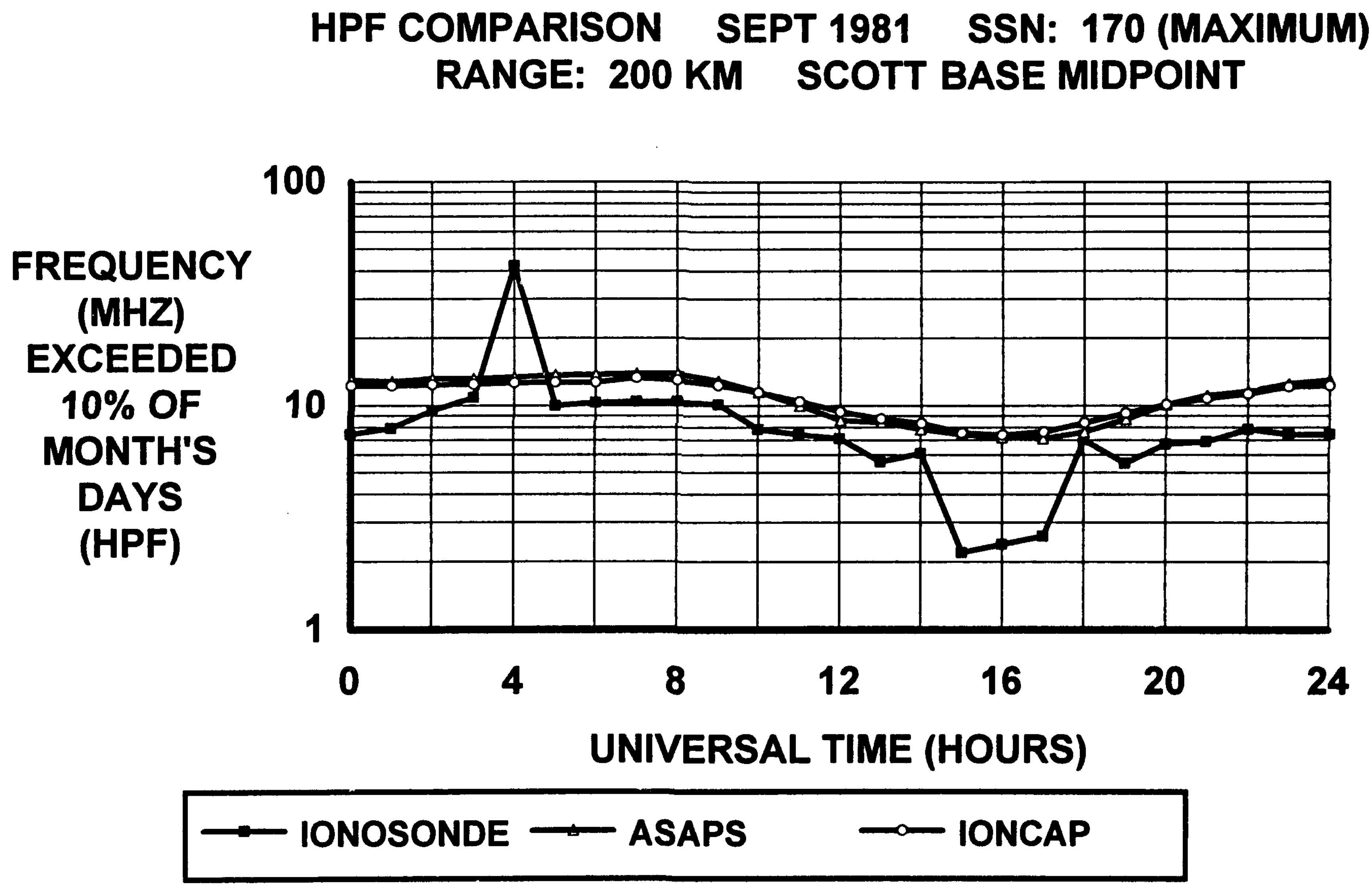
MUF COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT

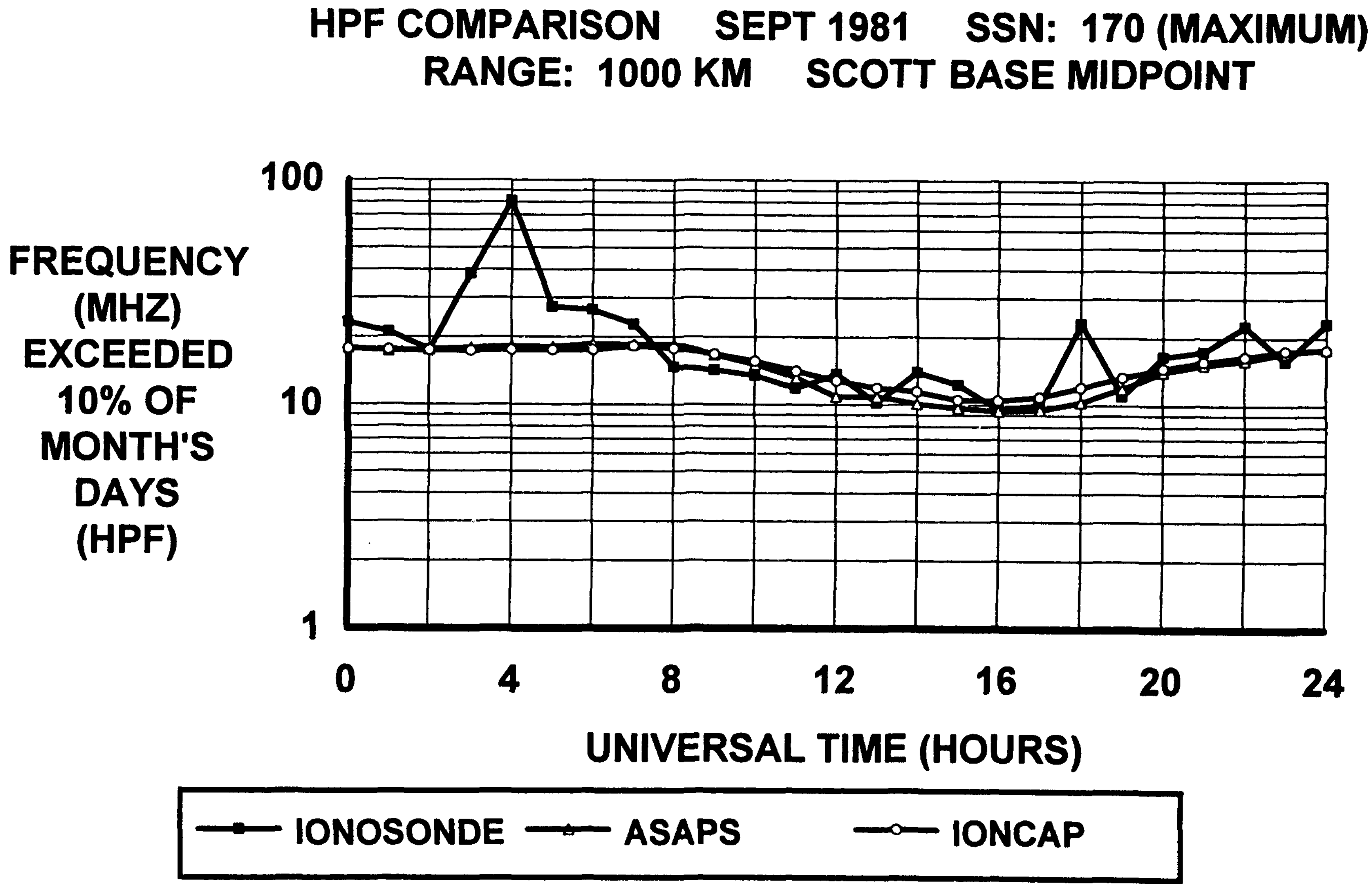


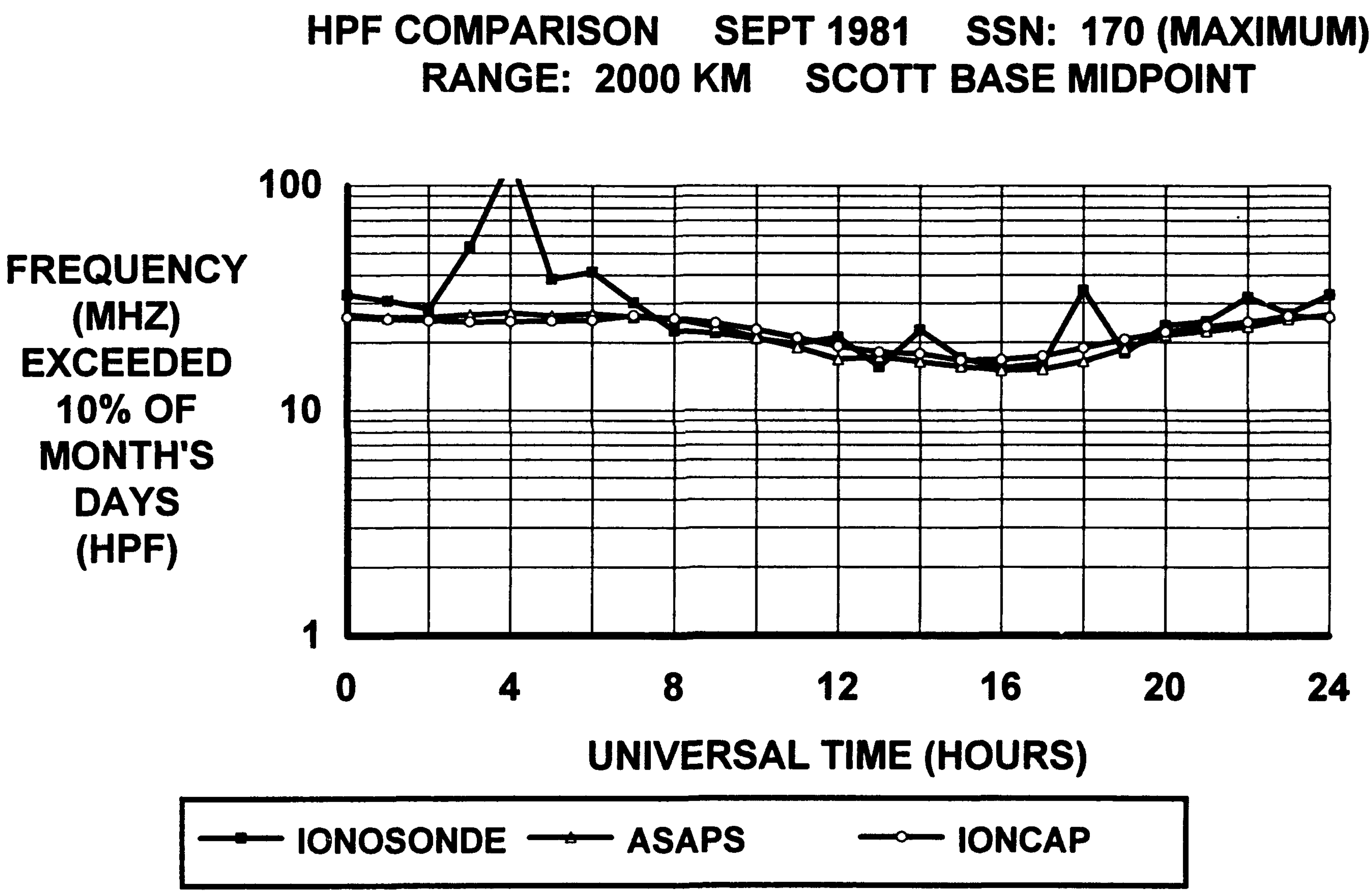
MUF COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT




HPF COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

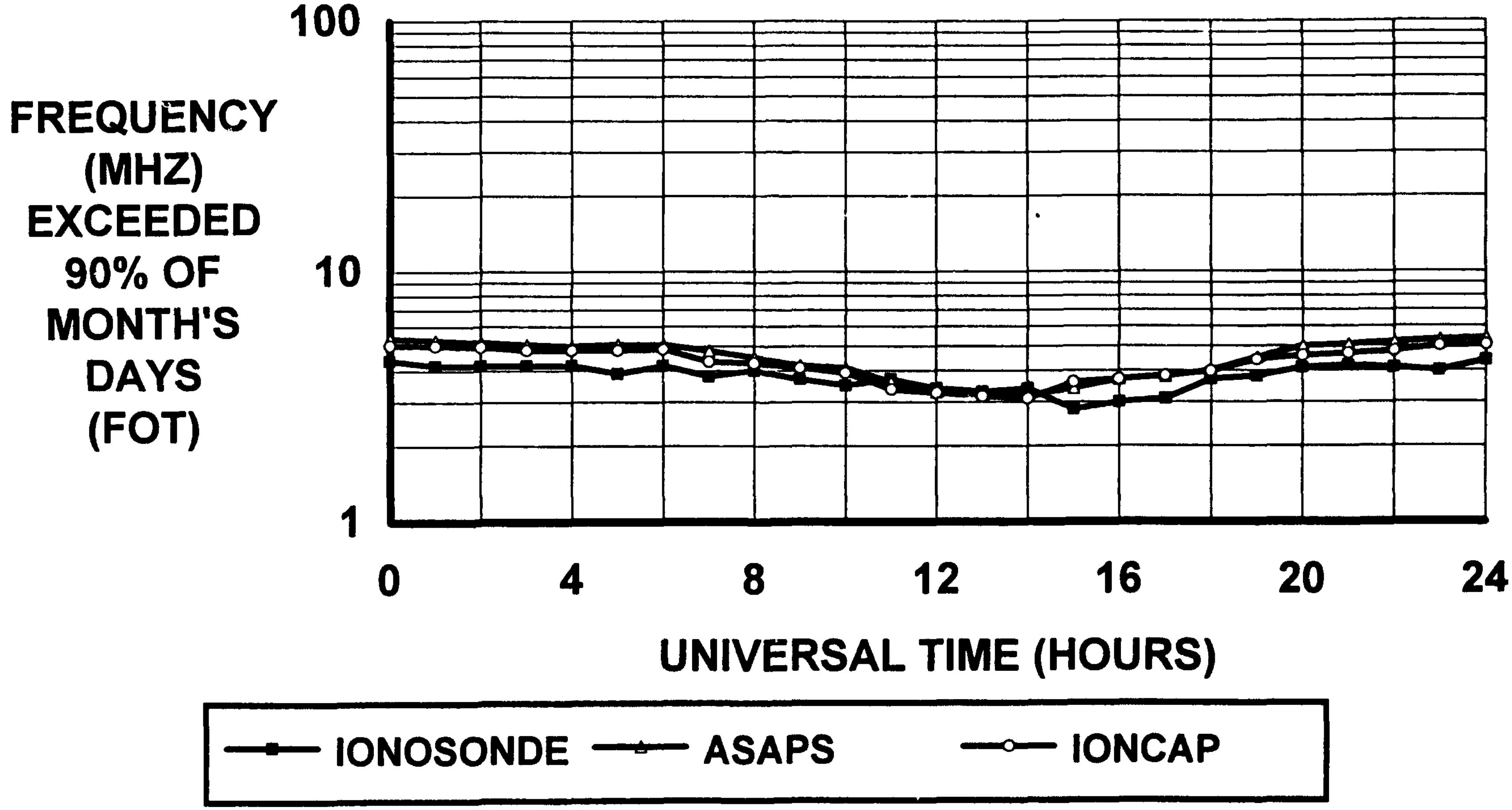

HPF COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


HPF COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

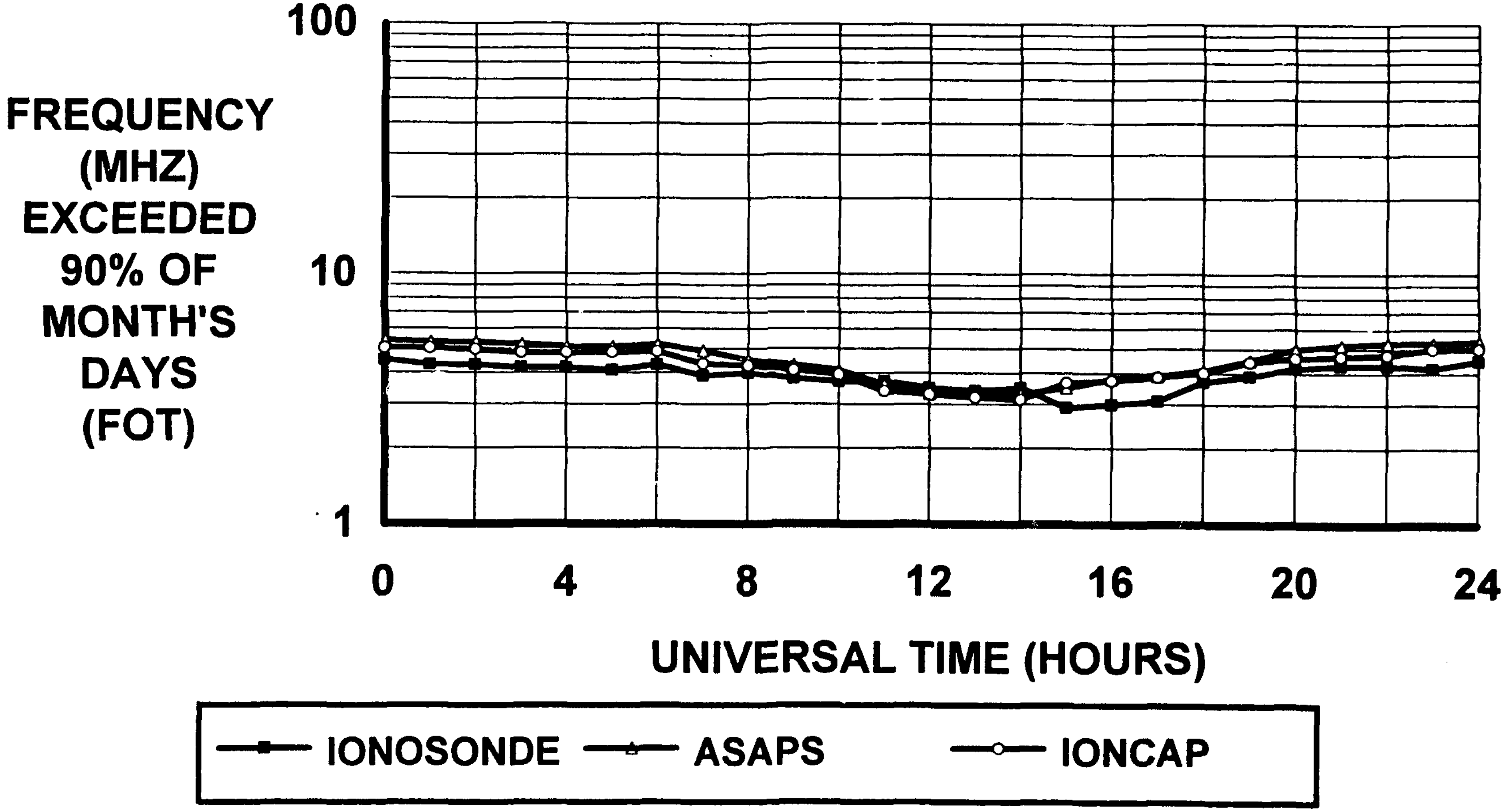

HPF COMPARISON SEPT 1981 SSN: 170 (MAXIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

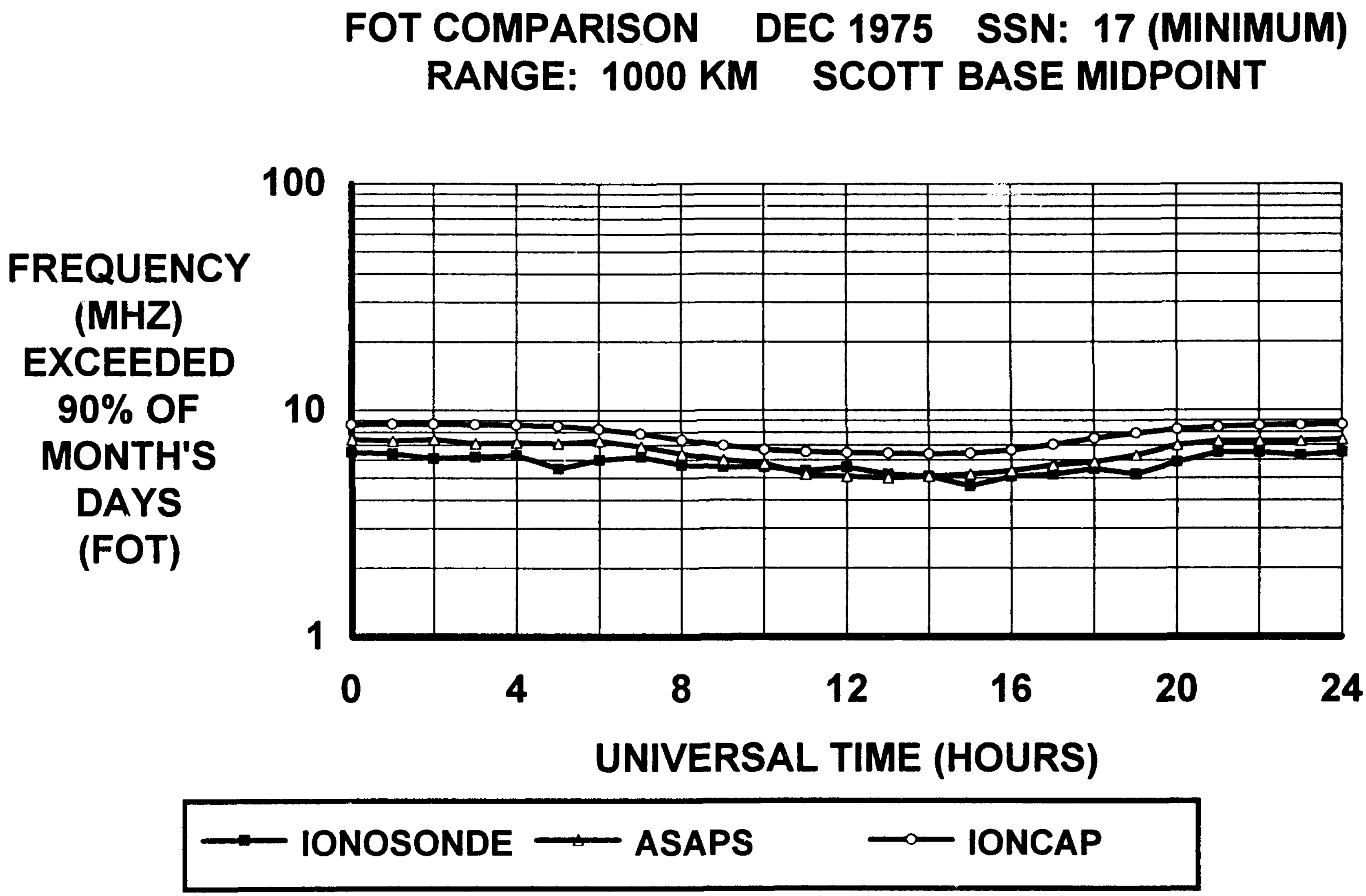
		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

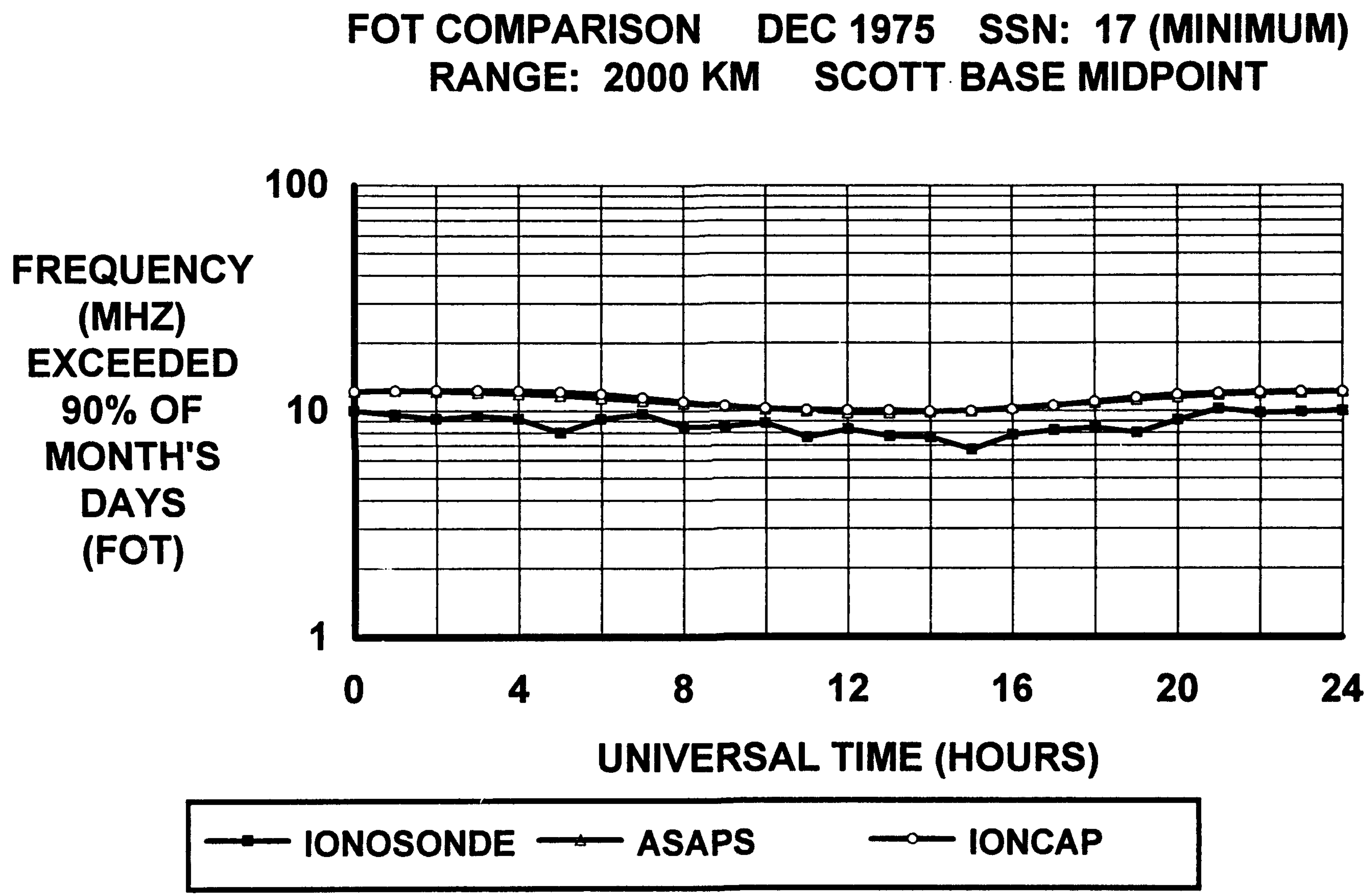
FOT COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT

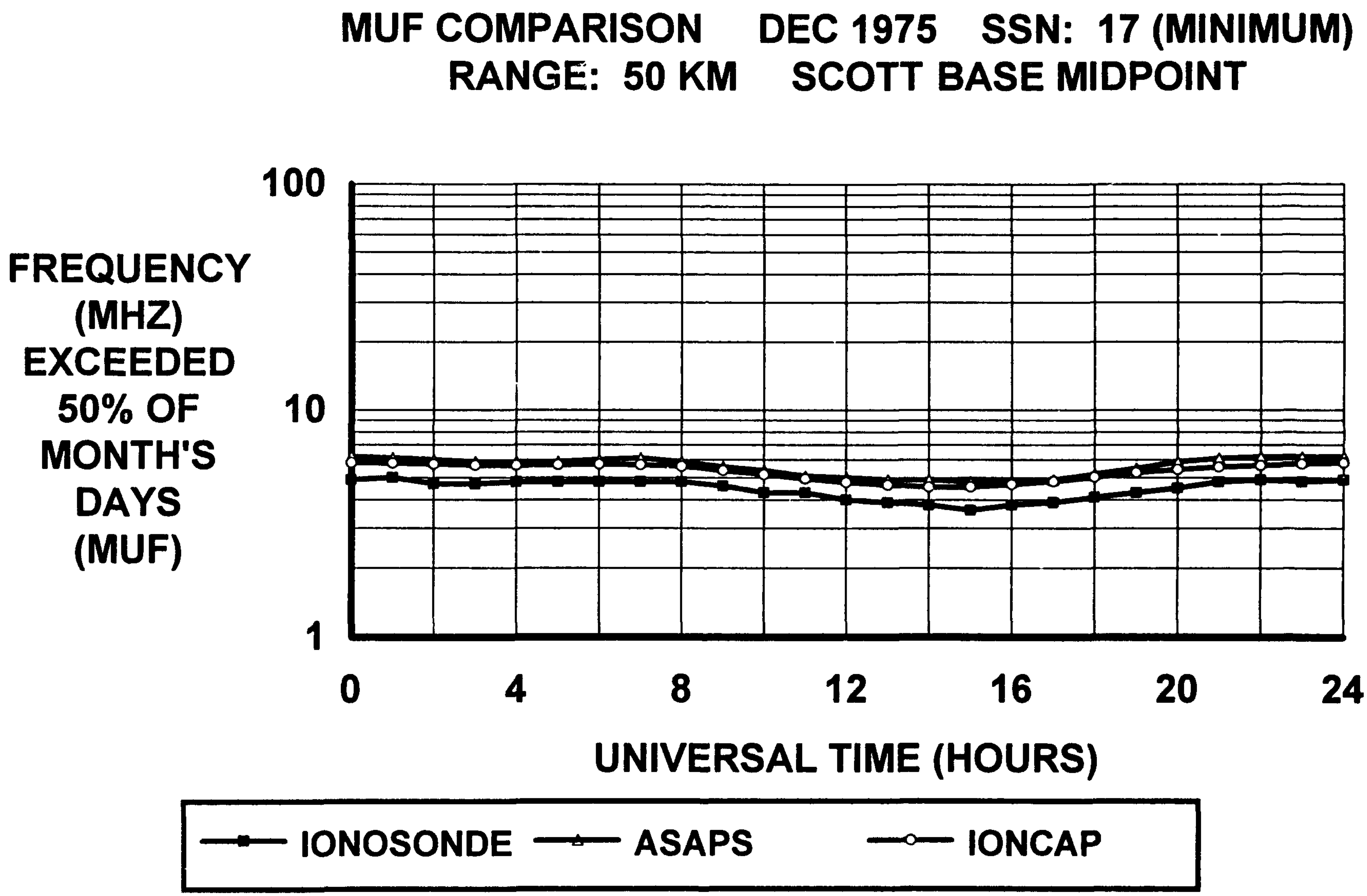


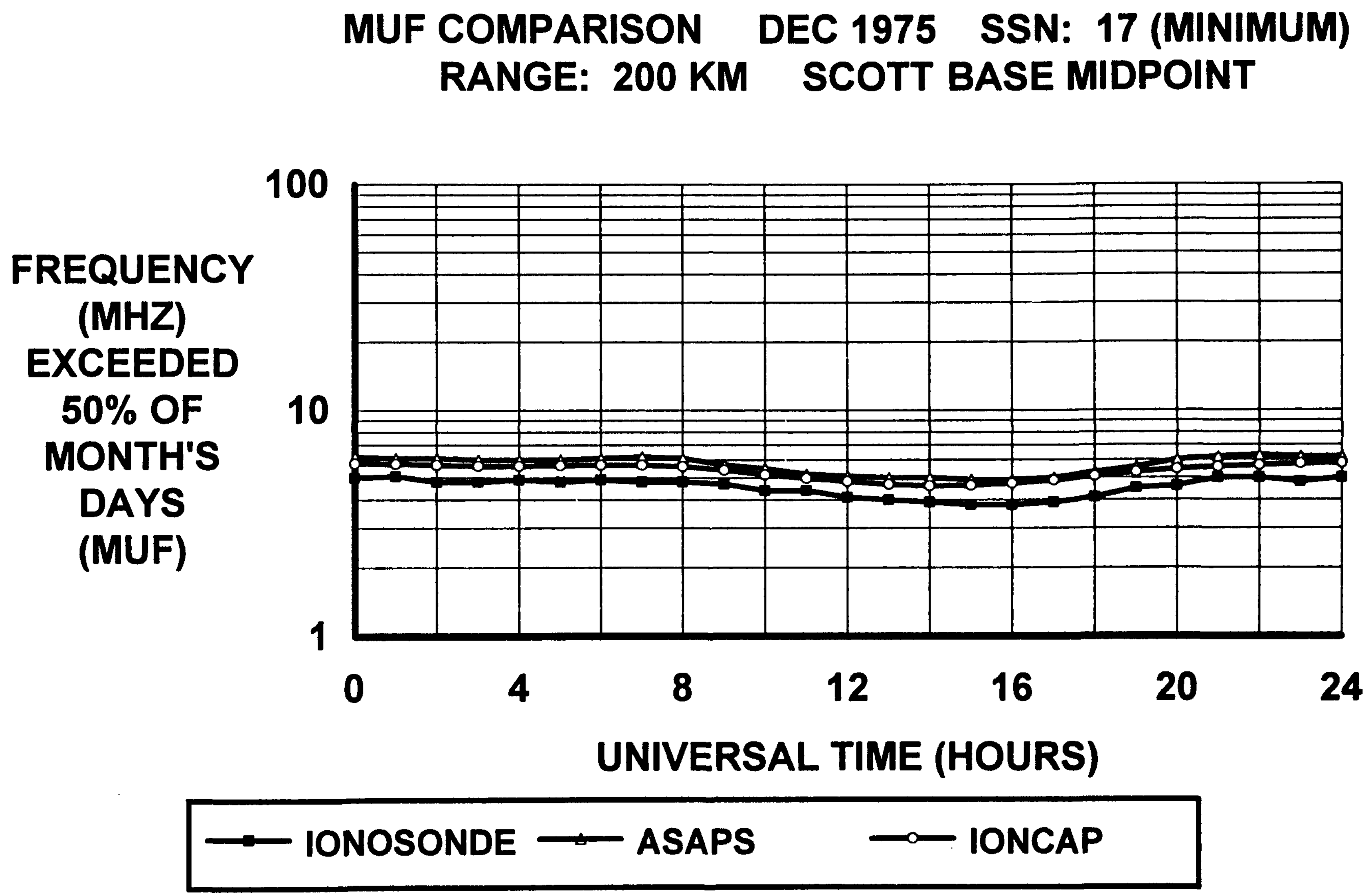
FOT COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT



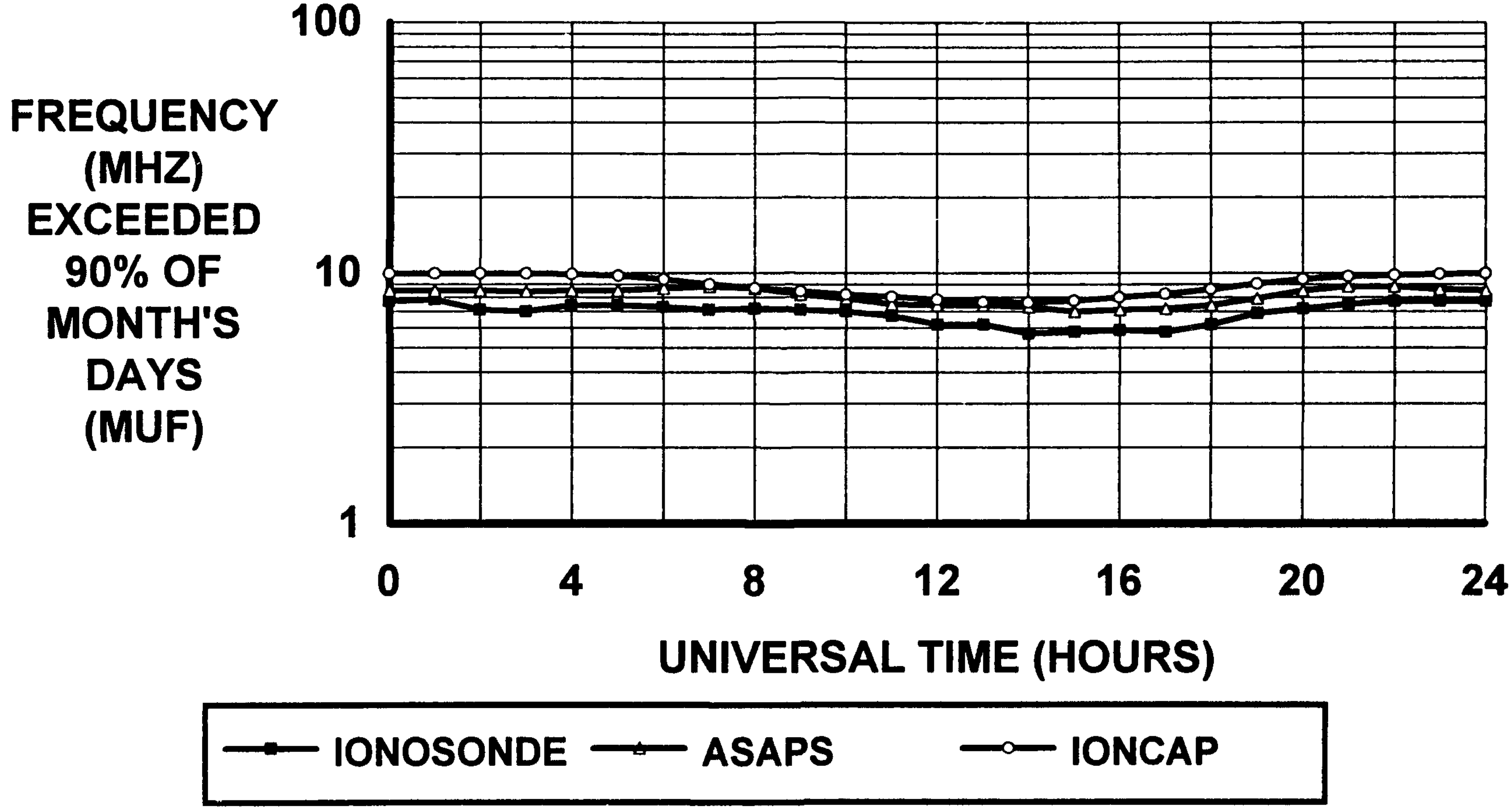

FOT COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

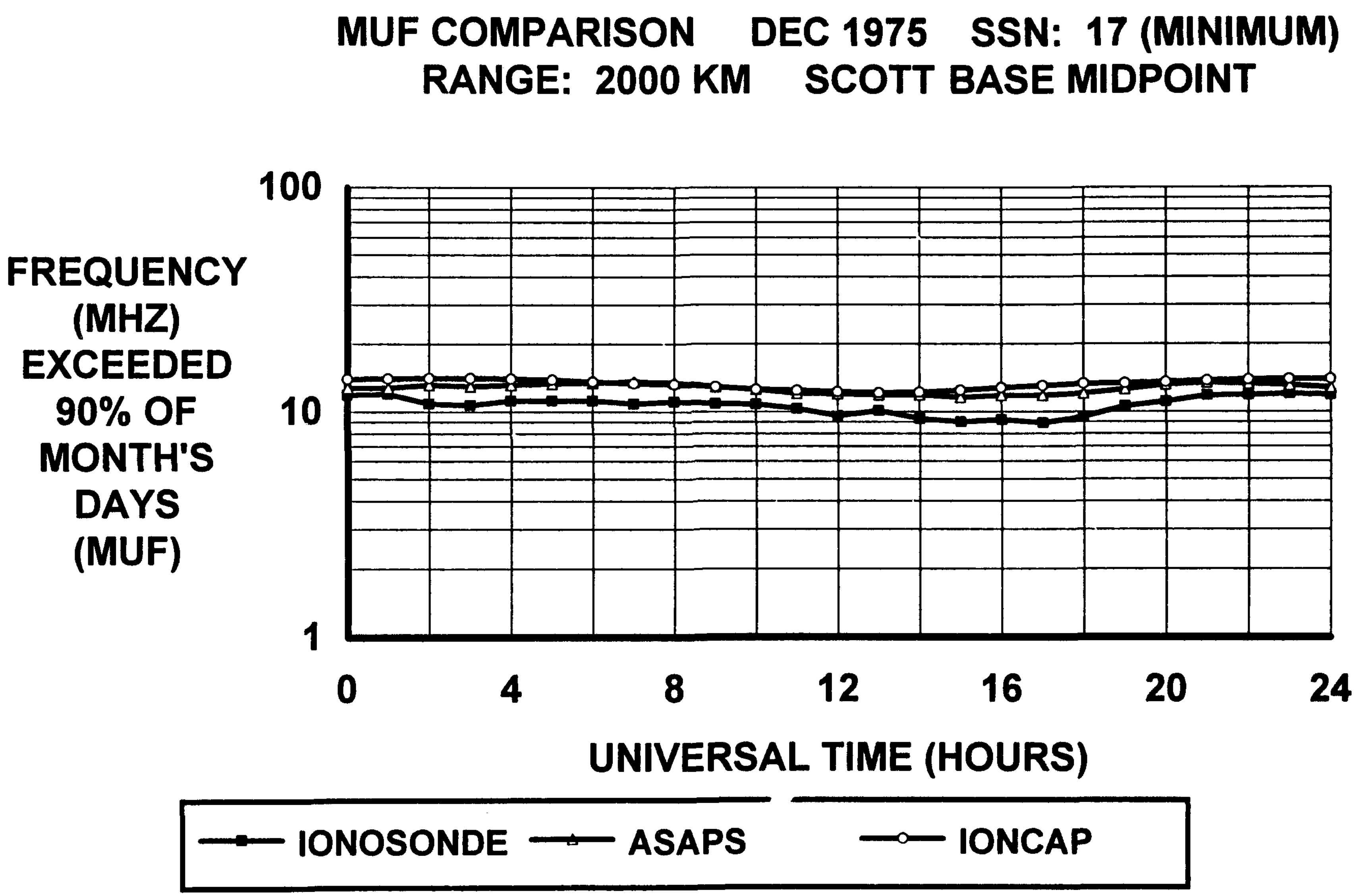

FOT COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


MUF COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

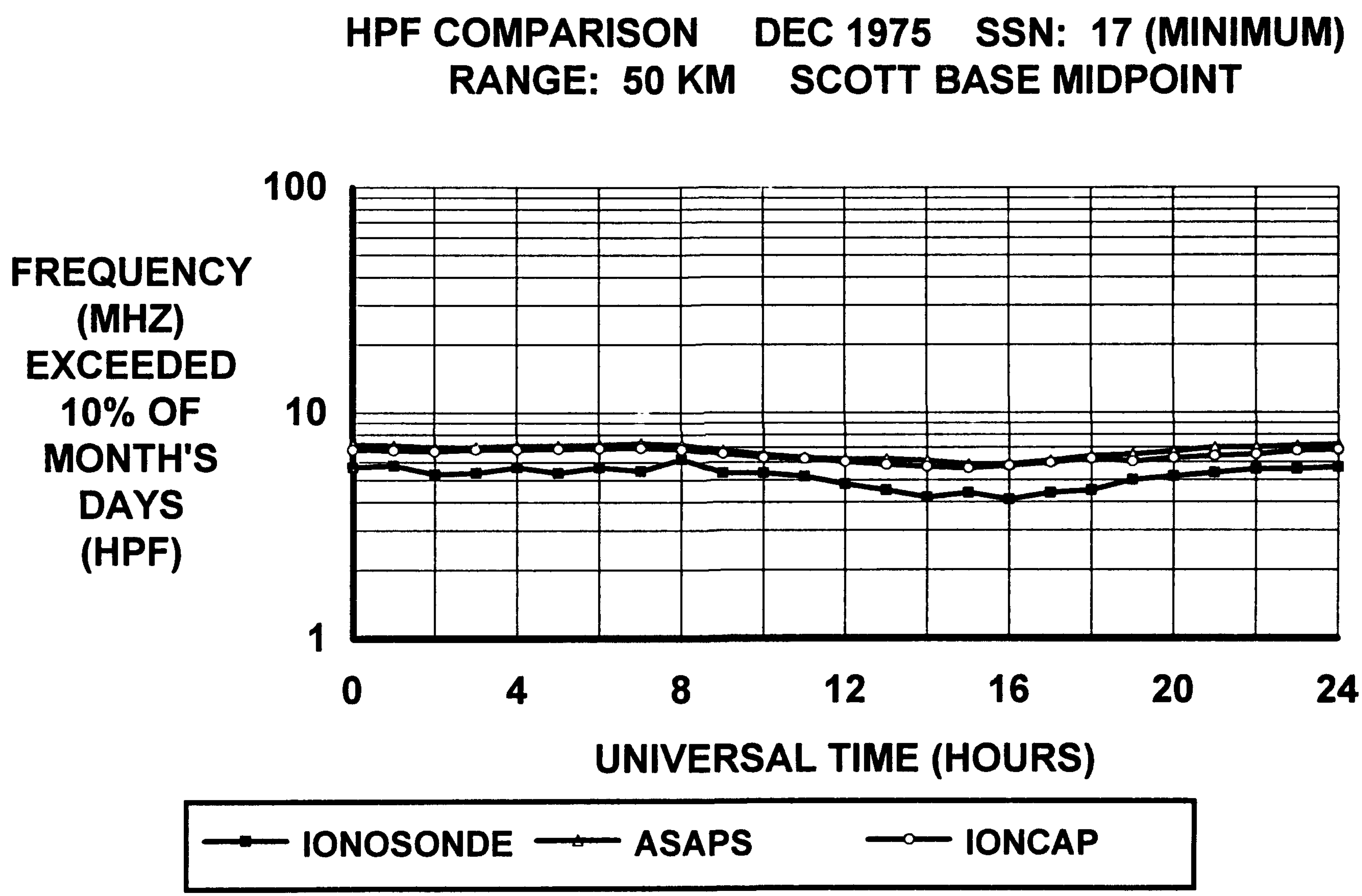

MUF COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

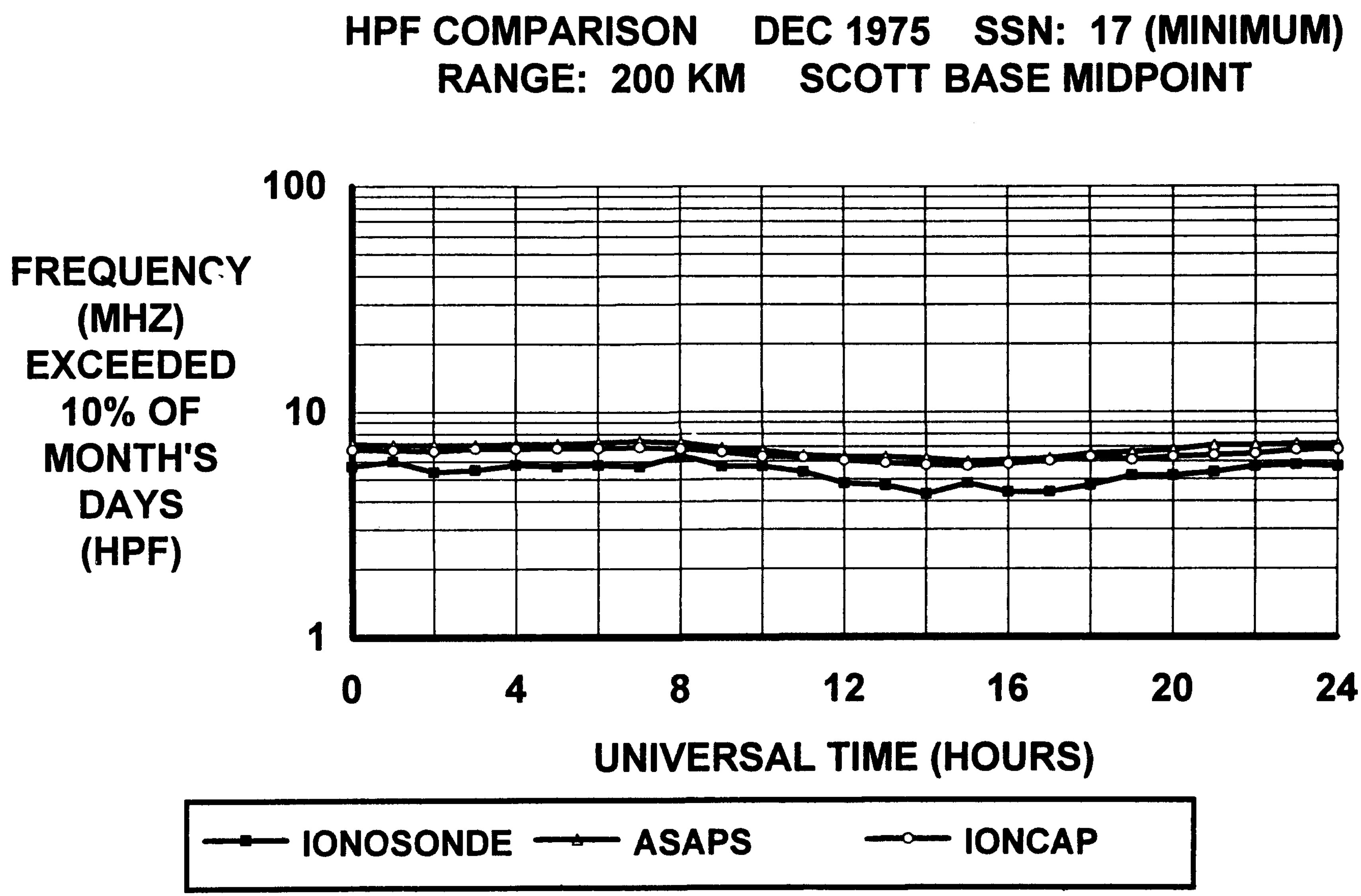
MUF COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT



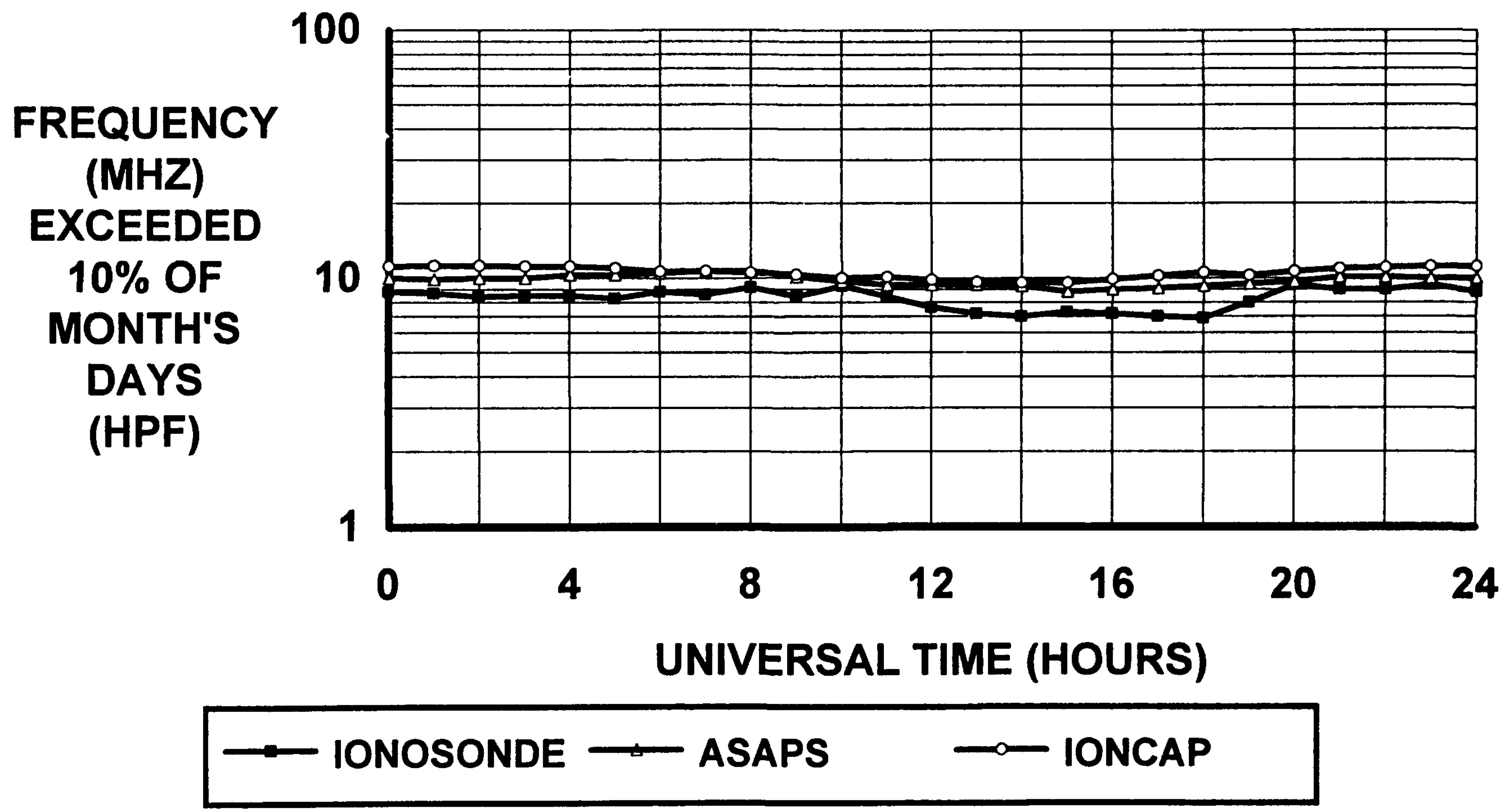


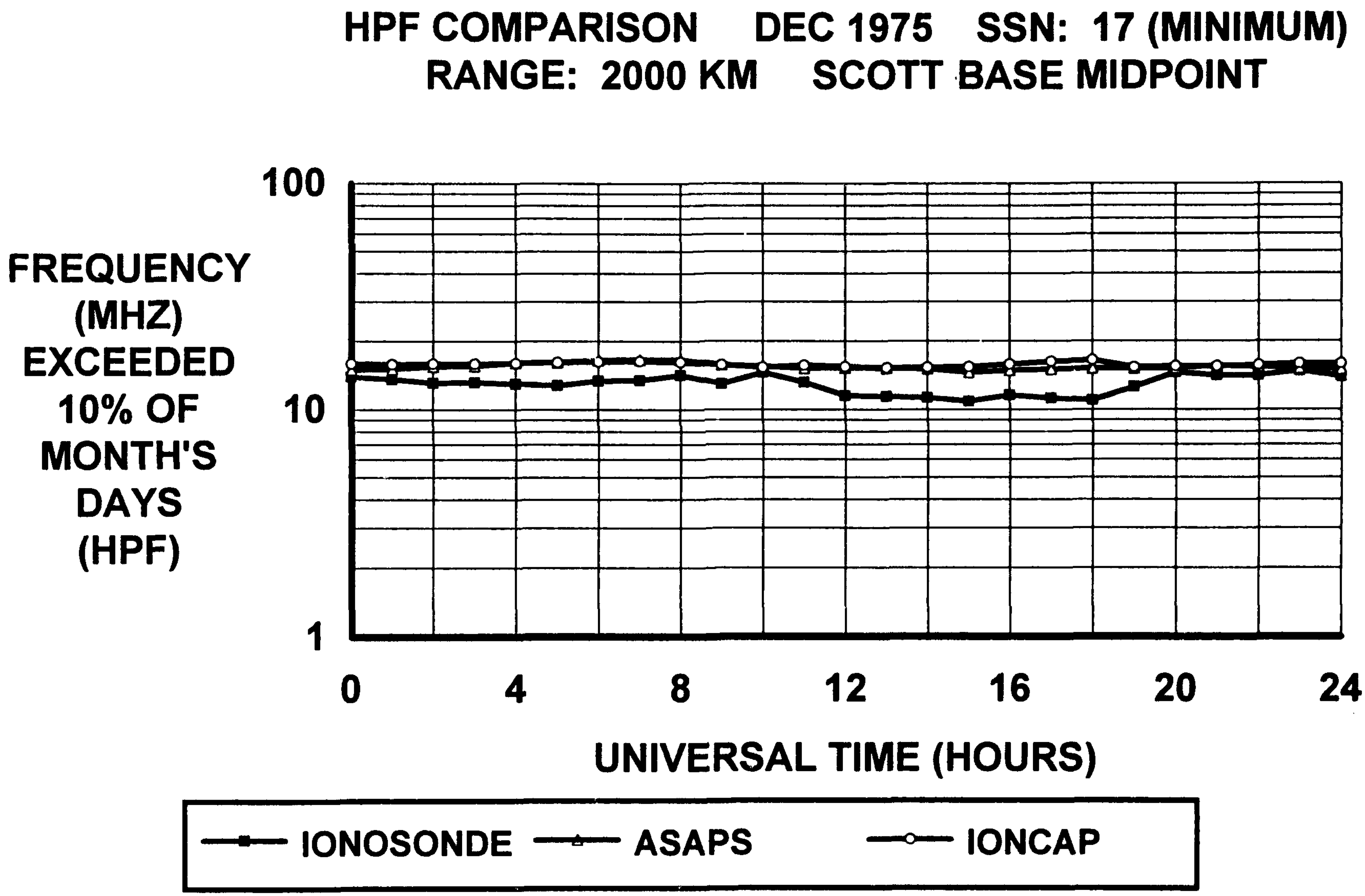
MUF COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


HPF COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


HPF COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

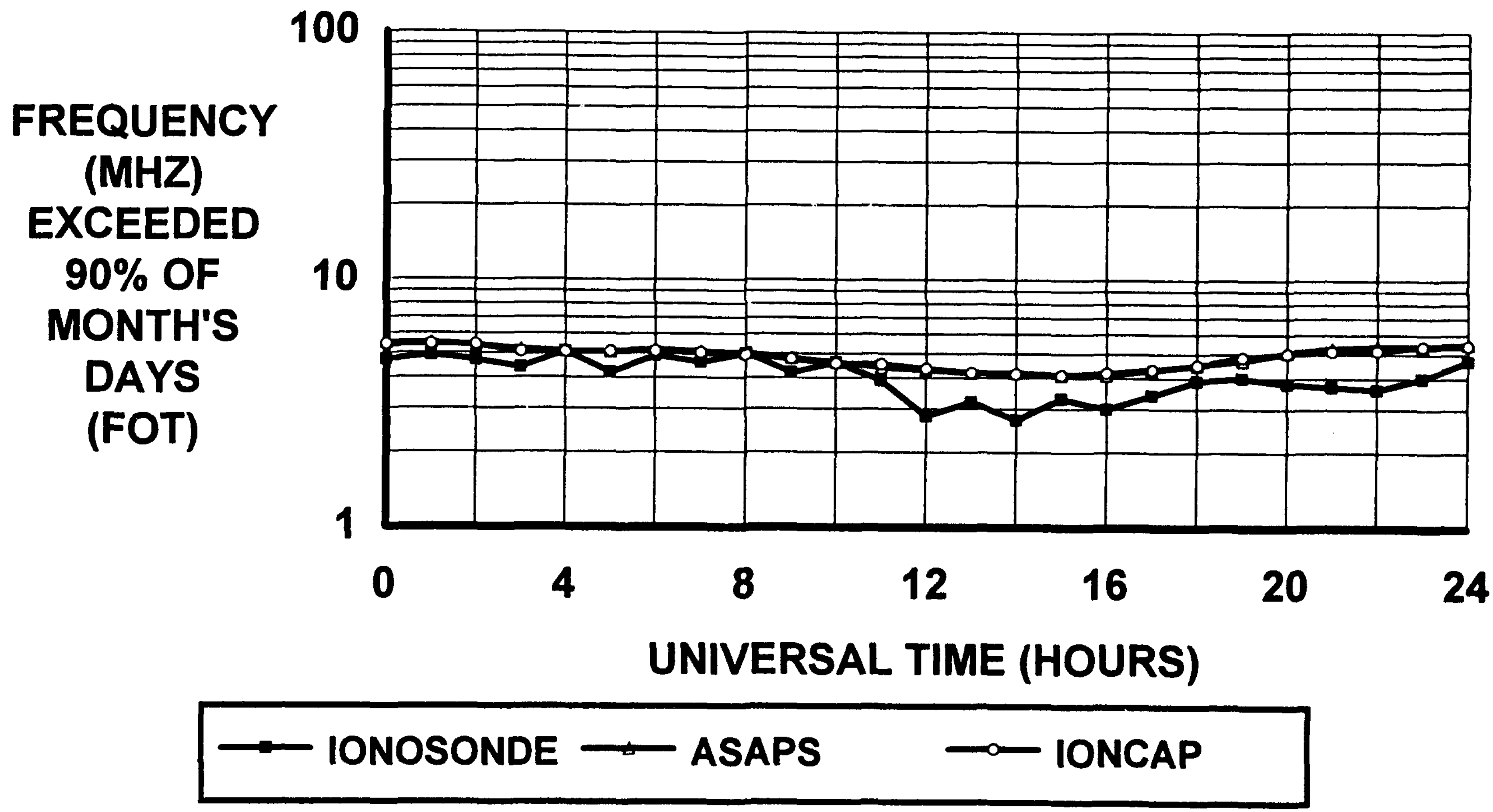
HPF COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT



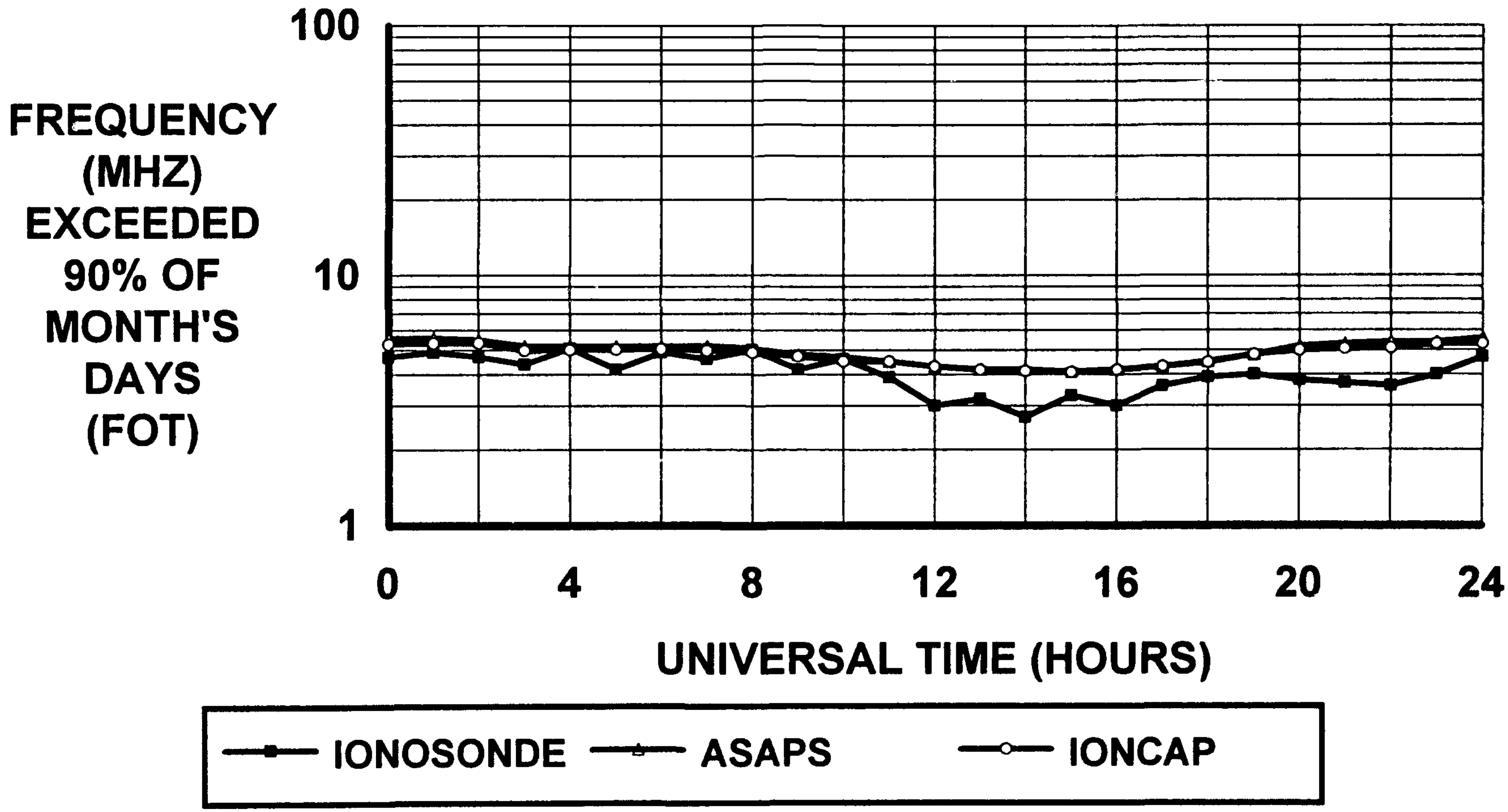

HPF COMPARISON DEC 1975 SSN: 17 (MINIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

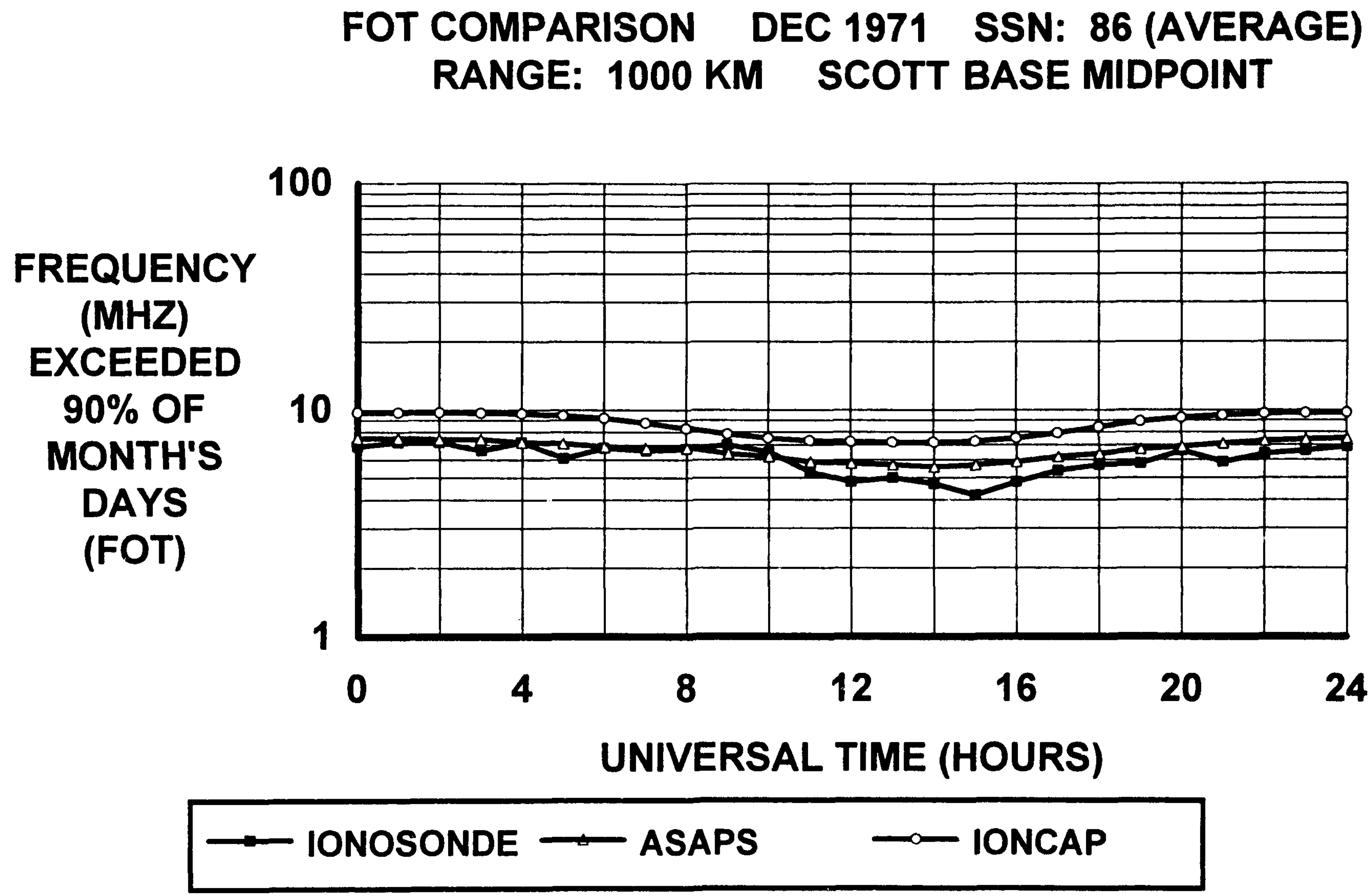
		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

FOT COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT

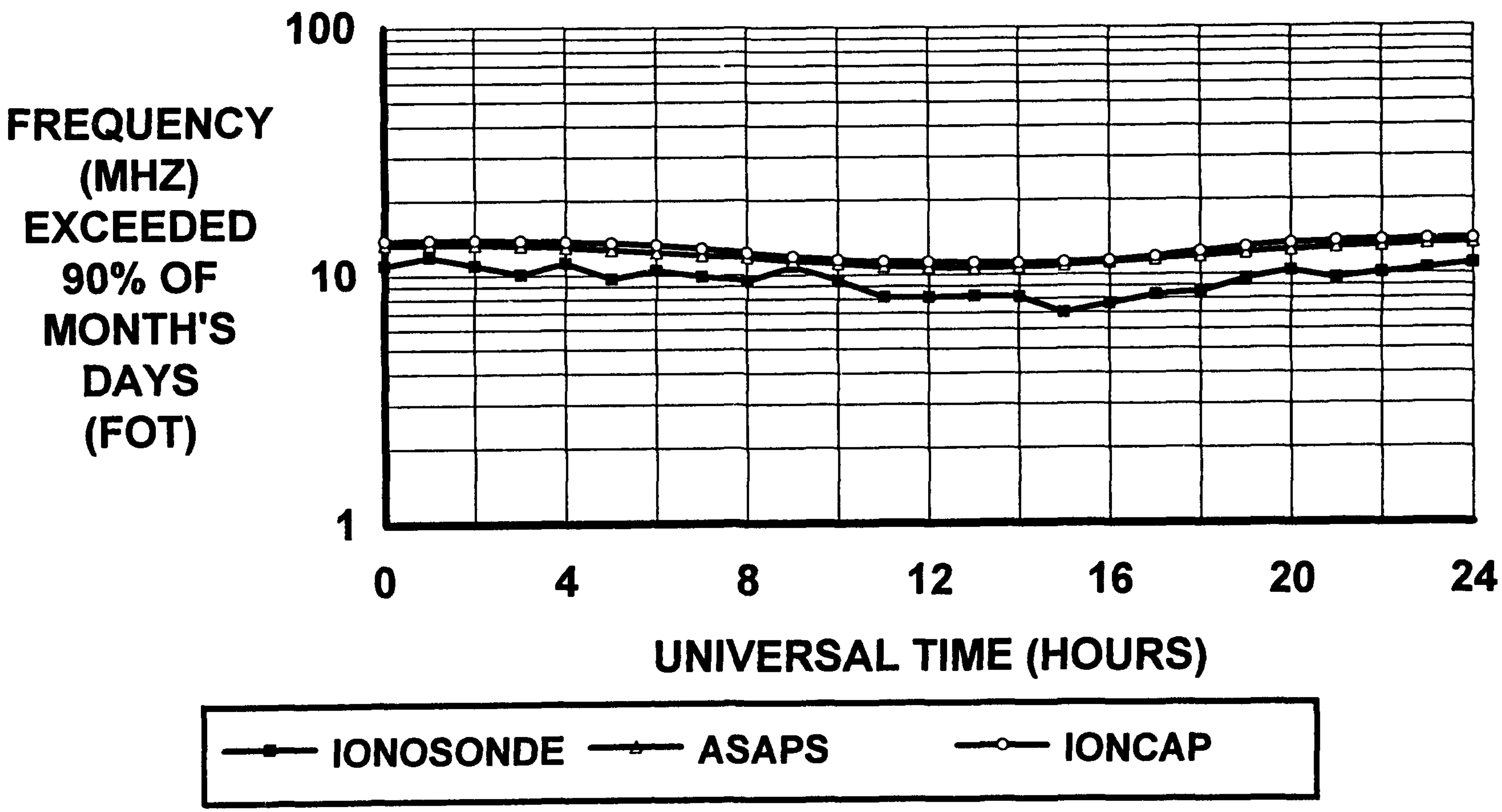


FOT COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT

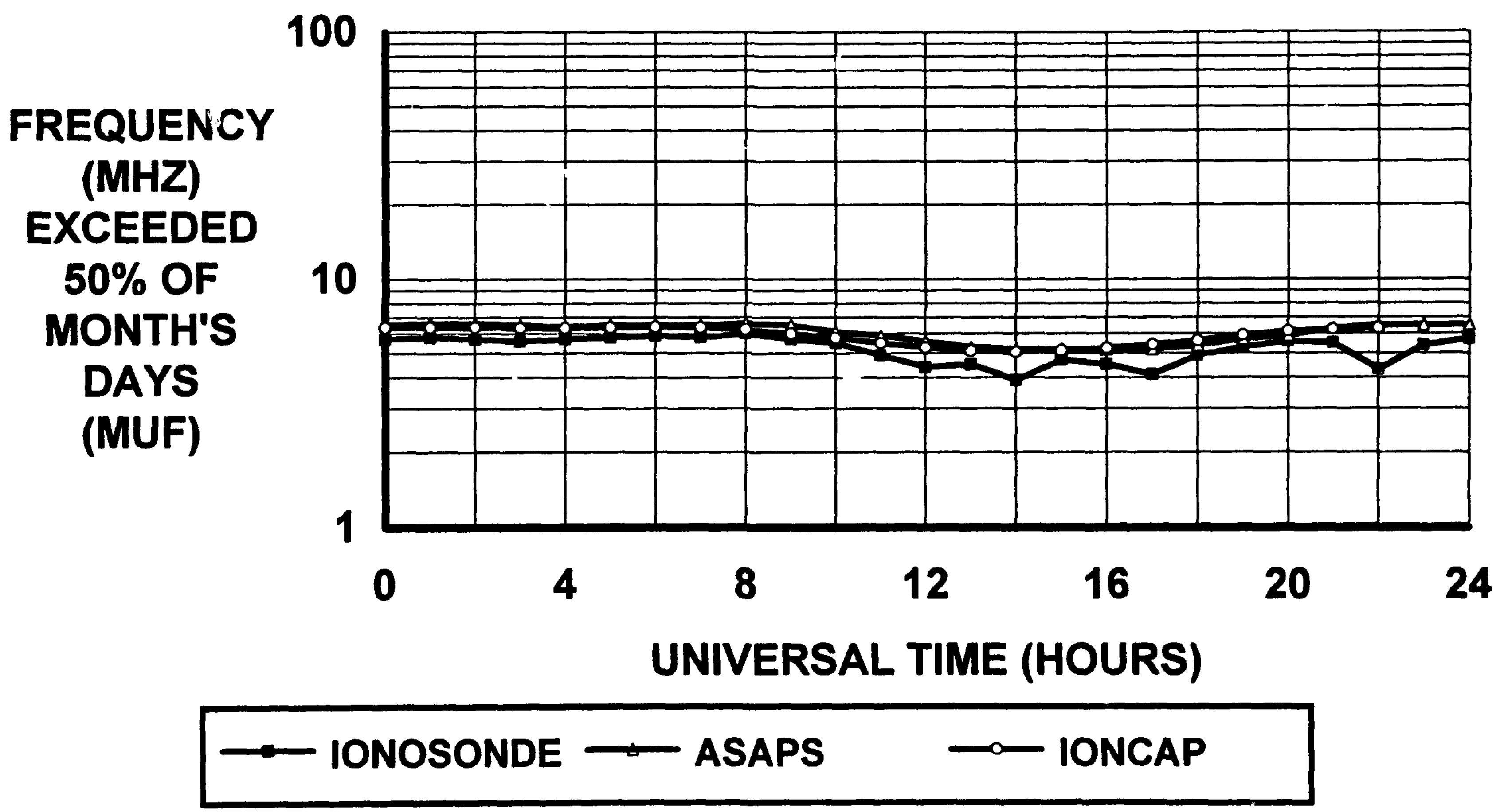



FOT COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

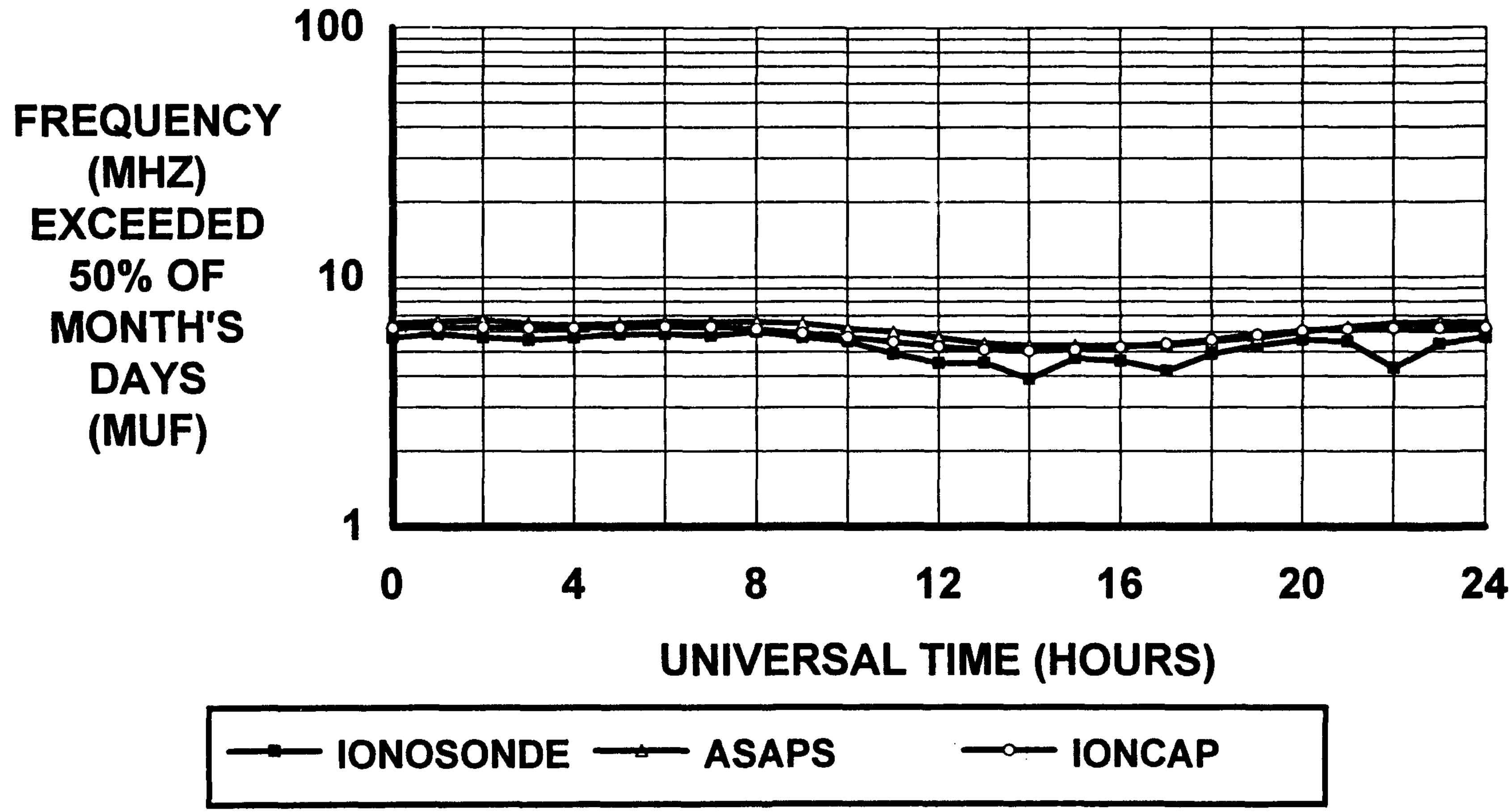
FOT COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT



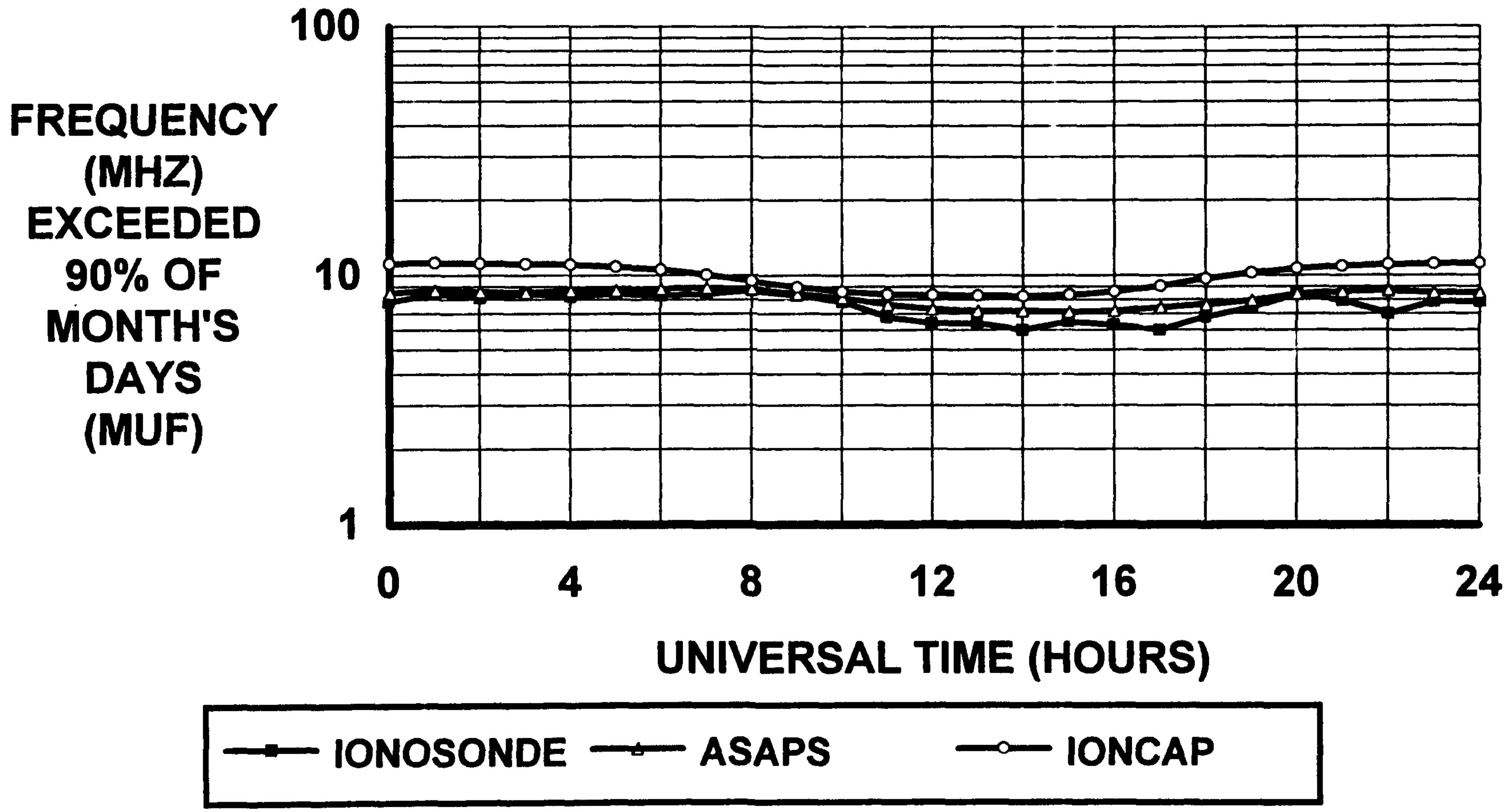
MUF COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT

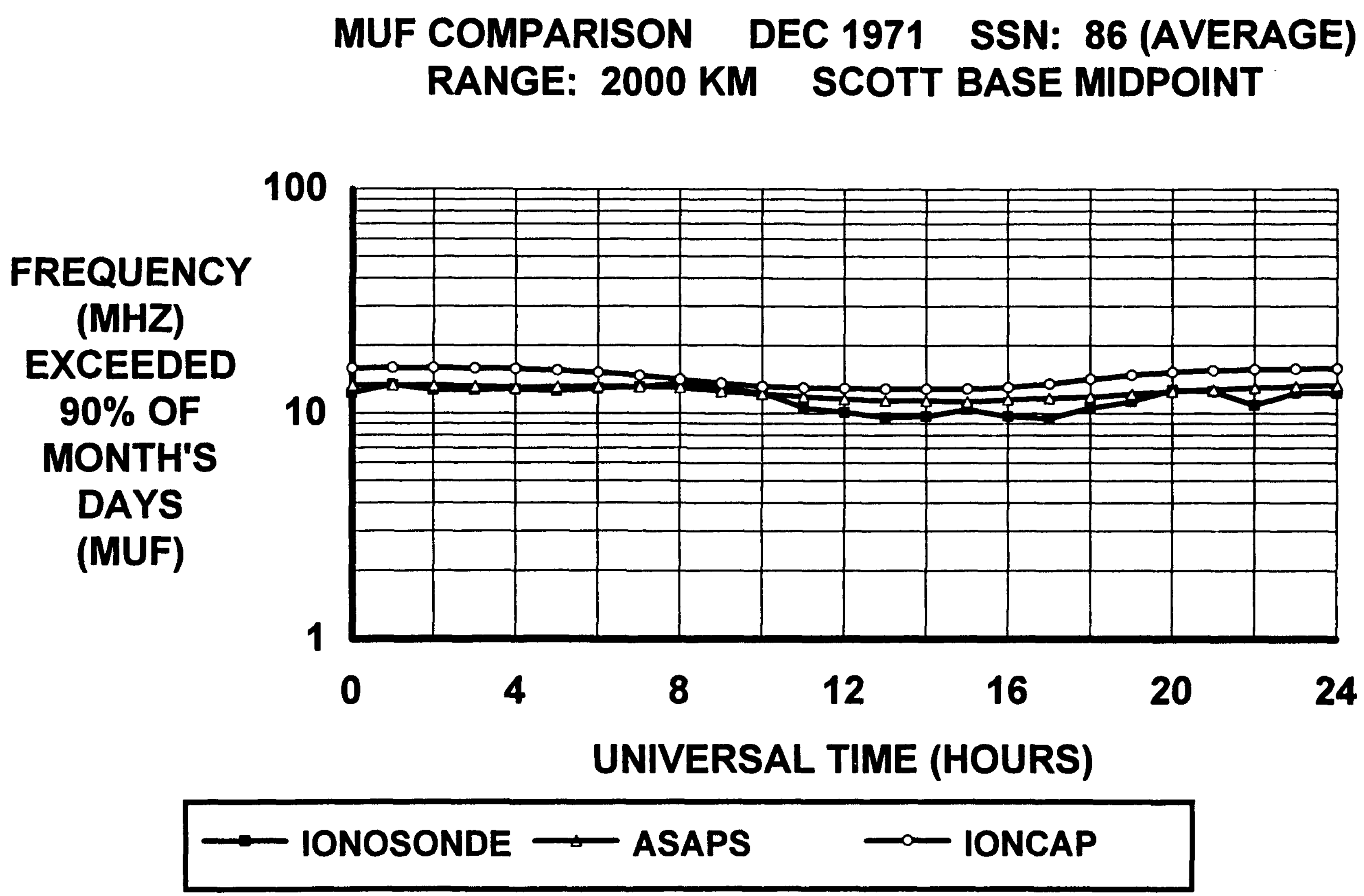


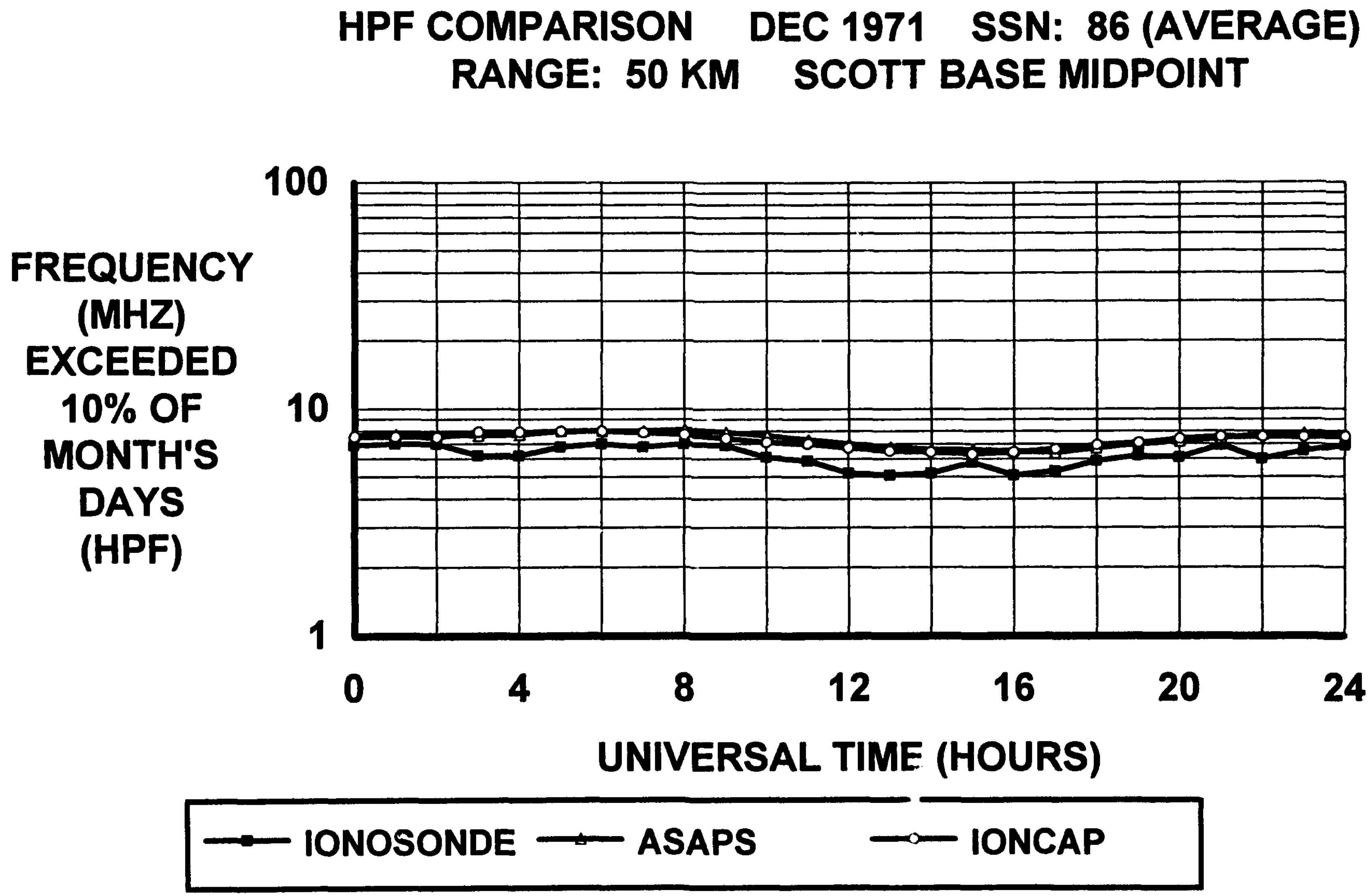
MUF COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT

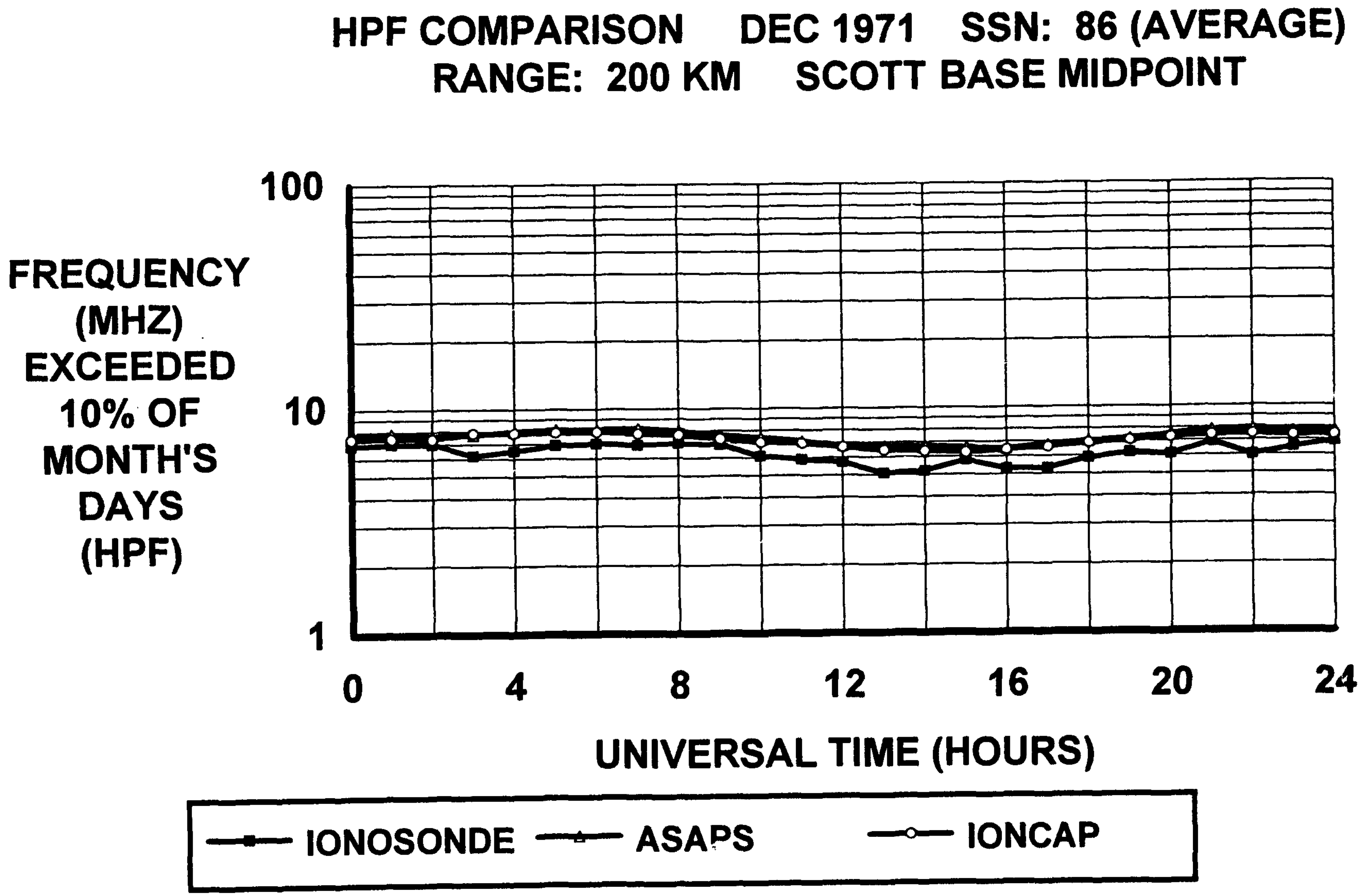


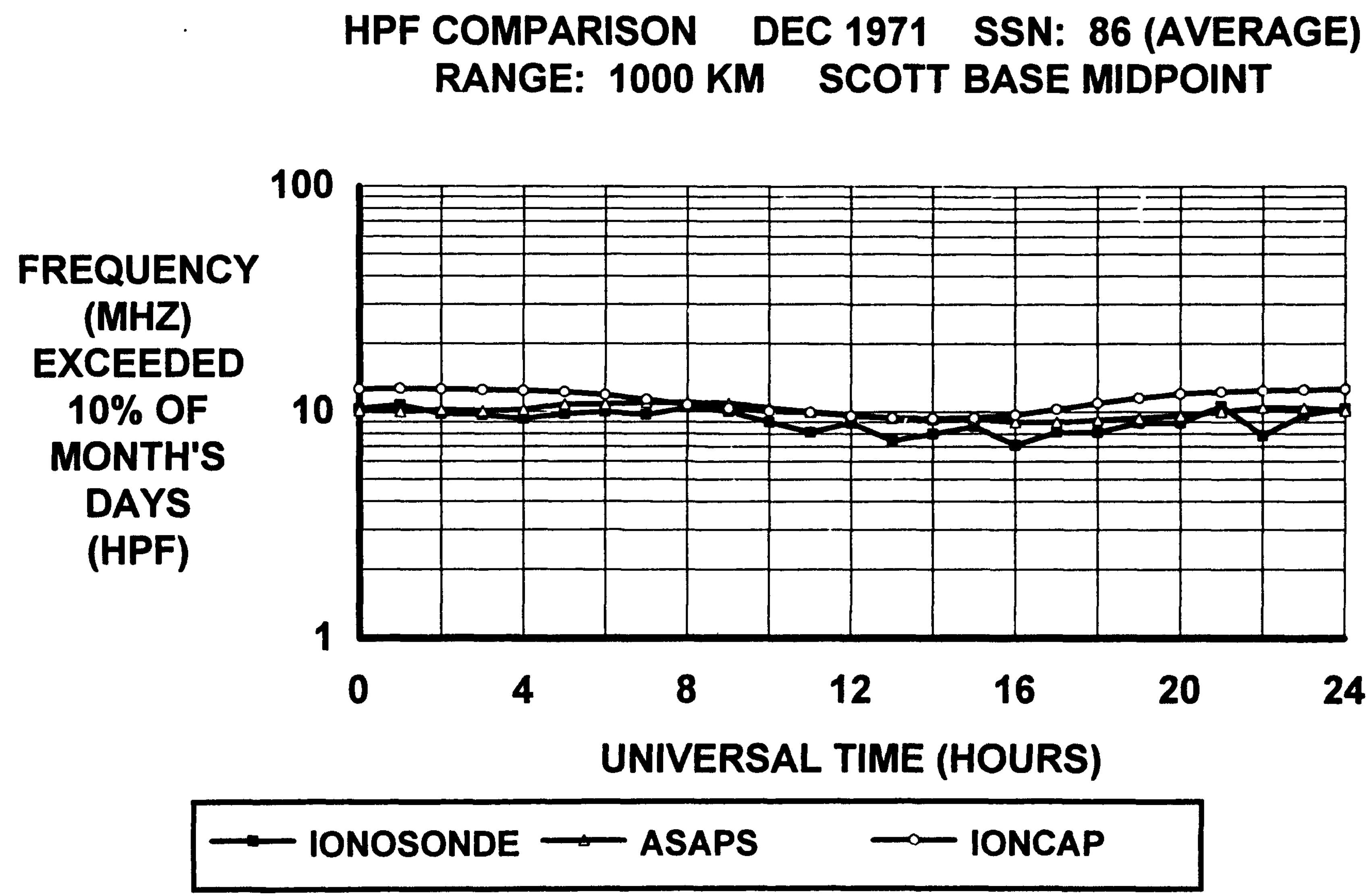
MUF COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 1000 KM SCOTT BASE MIDPOINT

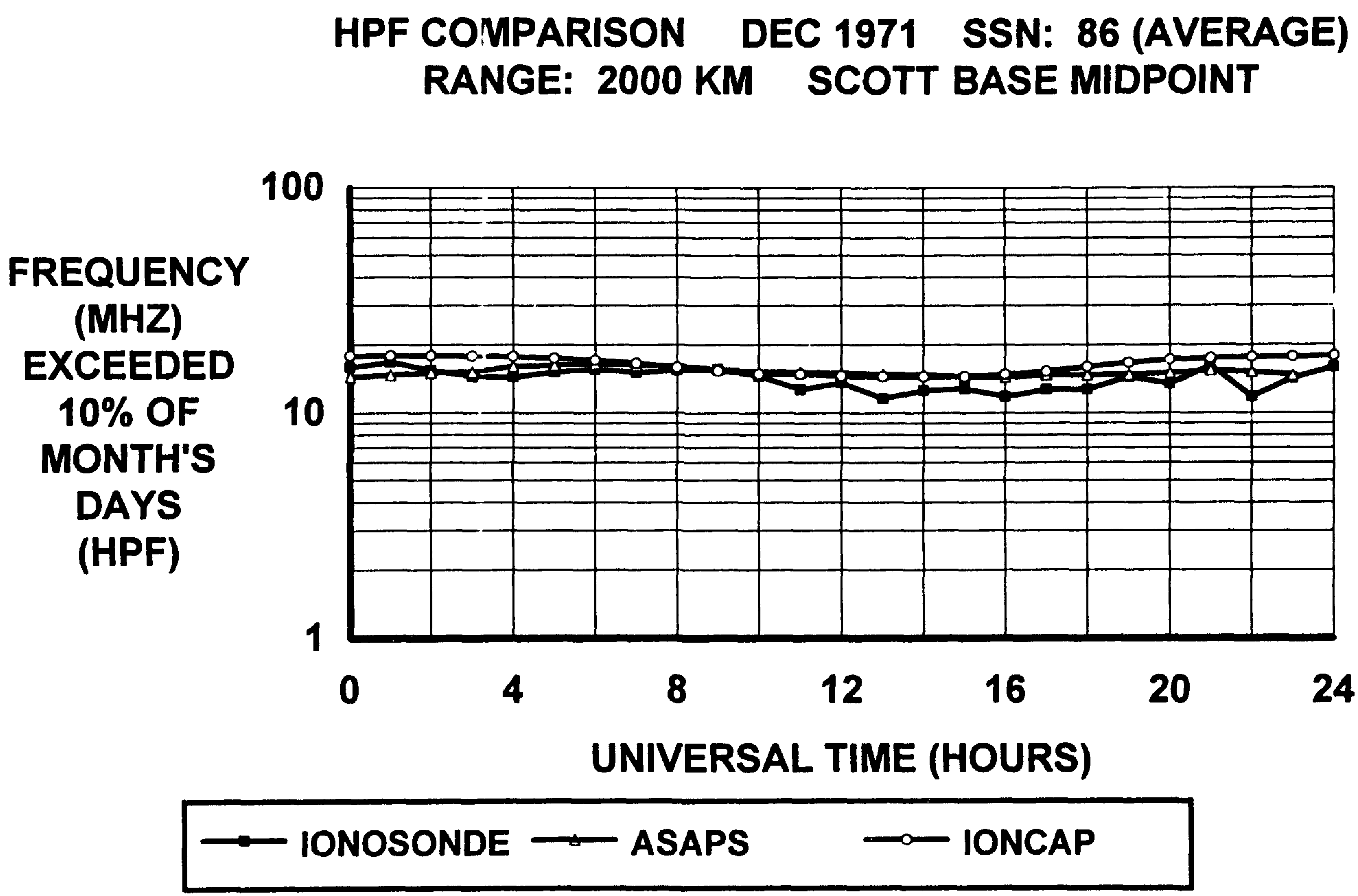



MUF COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (MUF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


HPF COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


HPF COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

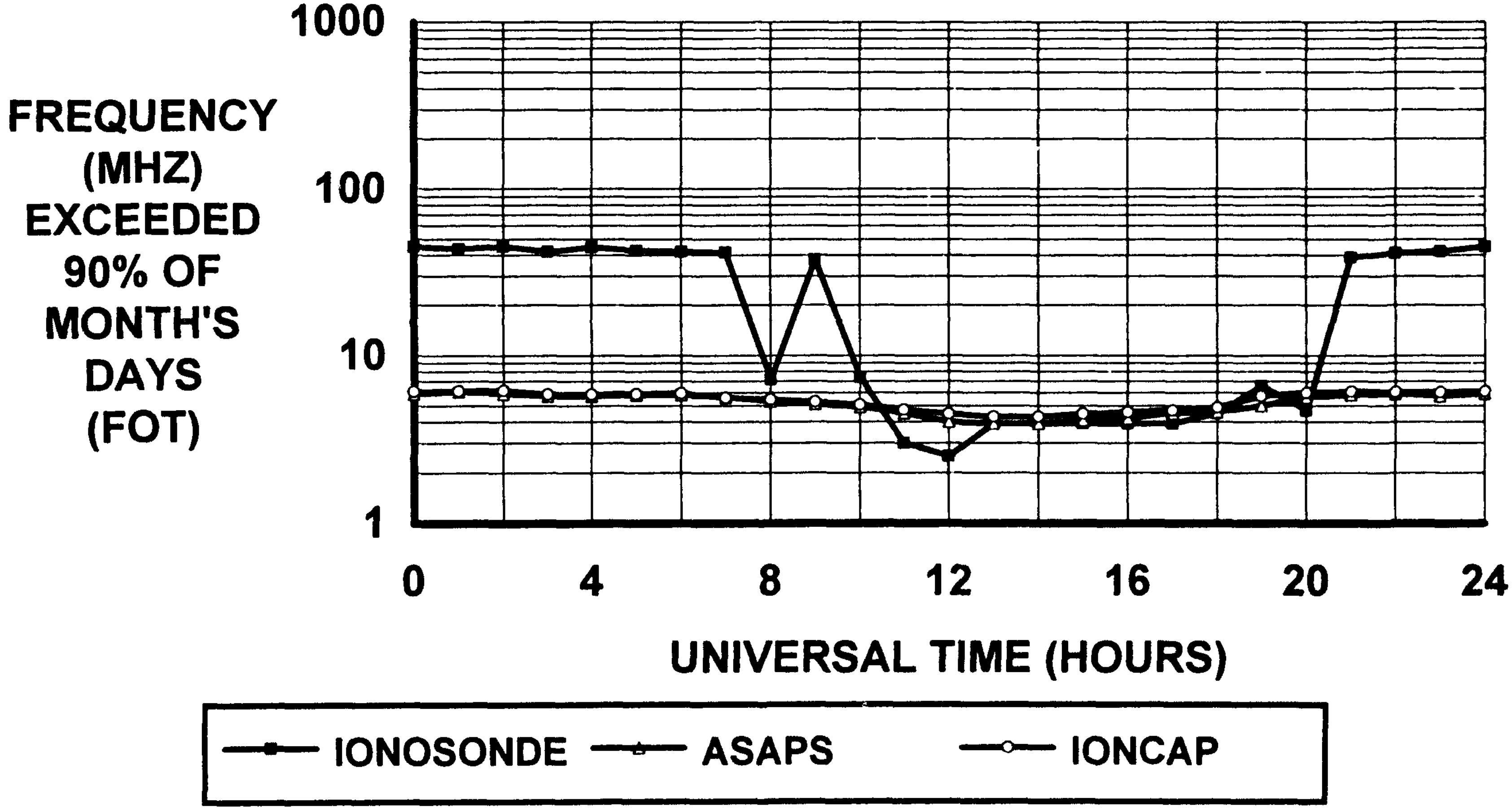

HPF COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 1000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

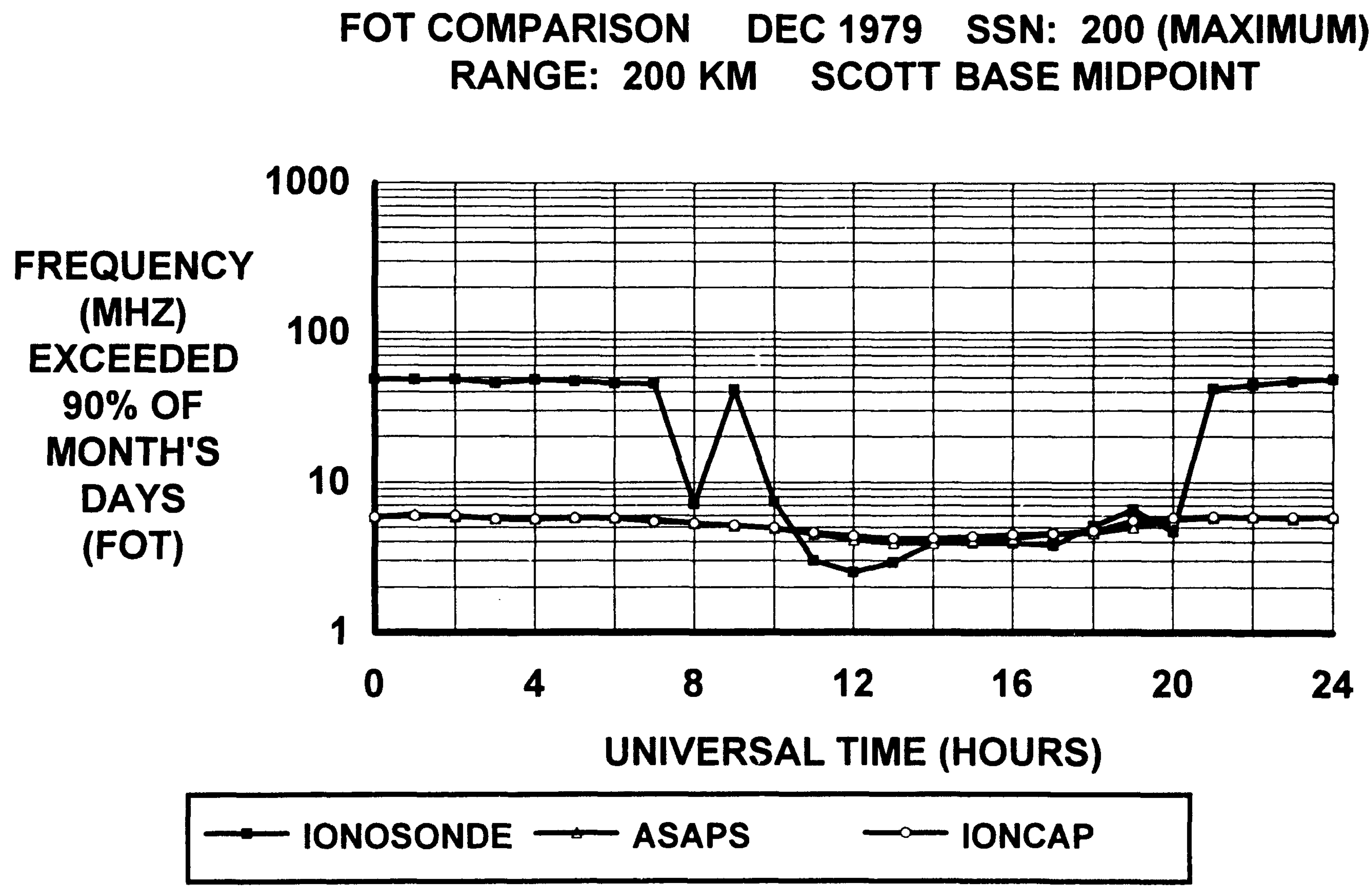


HPF COMPARISON DEC 1971 SSN: 86 (AVERAGE)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 10% OF MONTH'S DAYS (HPF)
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

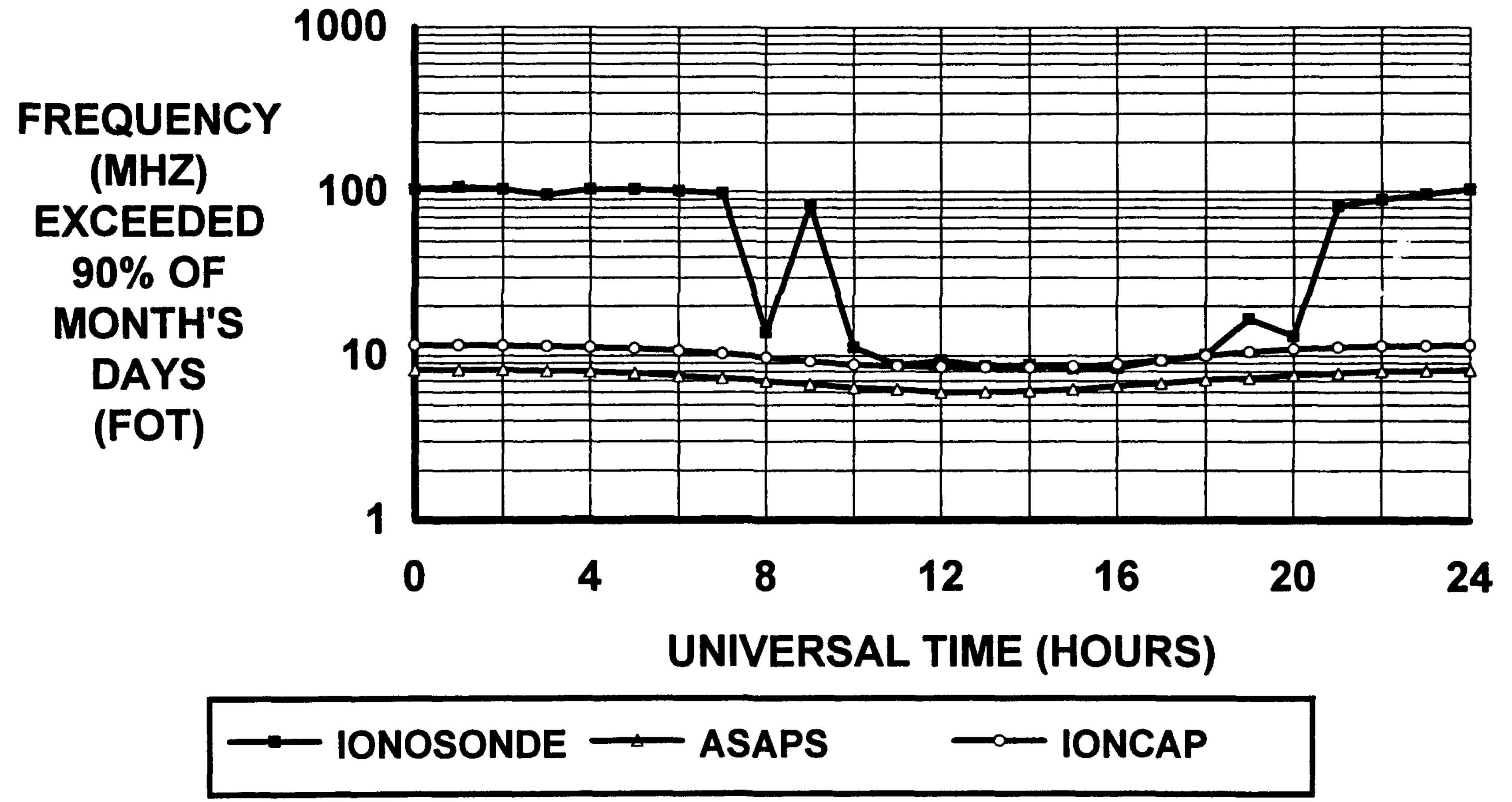
		MONTH							
		MARCH		JUNE		SEPTEMBER		DECEMBER	
	DIST PROB VALUE	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #	SSN / YEAR	PAGE # to PAGE #
MIN SSN VALUE	FOT	15 / 1977	D-6 to D-9	24 / 1975	D-45 to D-48	14 / 1975	D-84 to D-87	17 / 1975	D-123 to D-126
	MUF	15 / 1977	D-10 to D-13	24 1975	D-49 to D-52	14 1975	D-88 to D-91	17 / 1975	D-127 to D-130
	HPF	15 / 1977	D-14 to D-17	24 / 1975	D-53 to D-56	14 / 1975	D-92 to D-95	17 / 1975	D-131 to D-134
AVG SSN VALUE	FOT	79 / 1978	D-19 to D-22	77 / 1983	D-58 to D-61	63 / 1972	D-97 to D-100	86 / 1971	D-136 to D-139
	MUF	79 / 1978	D-23 to D-26	77 / 1983	D-62 to D-65	63 / 1972	D-101 to D-104	86 / 1971	D-140 to D-143
	HPF	79 / 1978	D-27 to D-30	77 / 1983	D-66 to D-69	63 / 1972	D-105 to D-108	86 / 1971	D-144 to D-147
MAX SSN VALUE	FOT	164 / 1982	D-32 to D-35	151 / 1980	D-71 to D-74	170 / 1981	D-110 to D-113	200 / 1979	D-149 to D-152
	MUF	164 / 1982	D-36 to D-39	151 / 1980	D-75 to D-78	170 / 1981	D-114 to D-117	200 / 1979	D-153 to D-156
	HPF	164 / 1982	D-40 to D-43	151 / 1980	D-79 to D-82	170 / 1981	D-118 to D-121	200 / 1979	D-157 to D-160

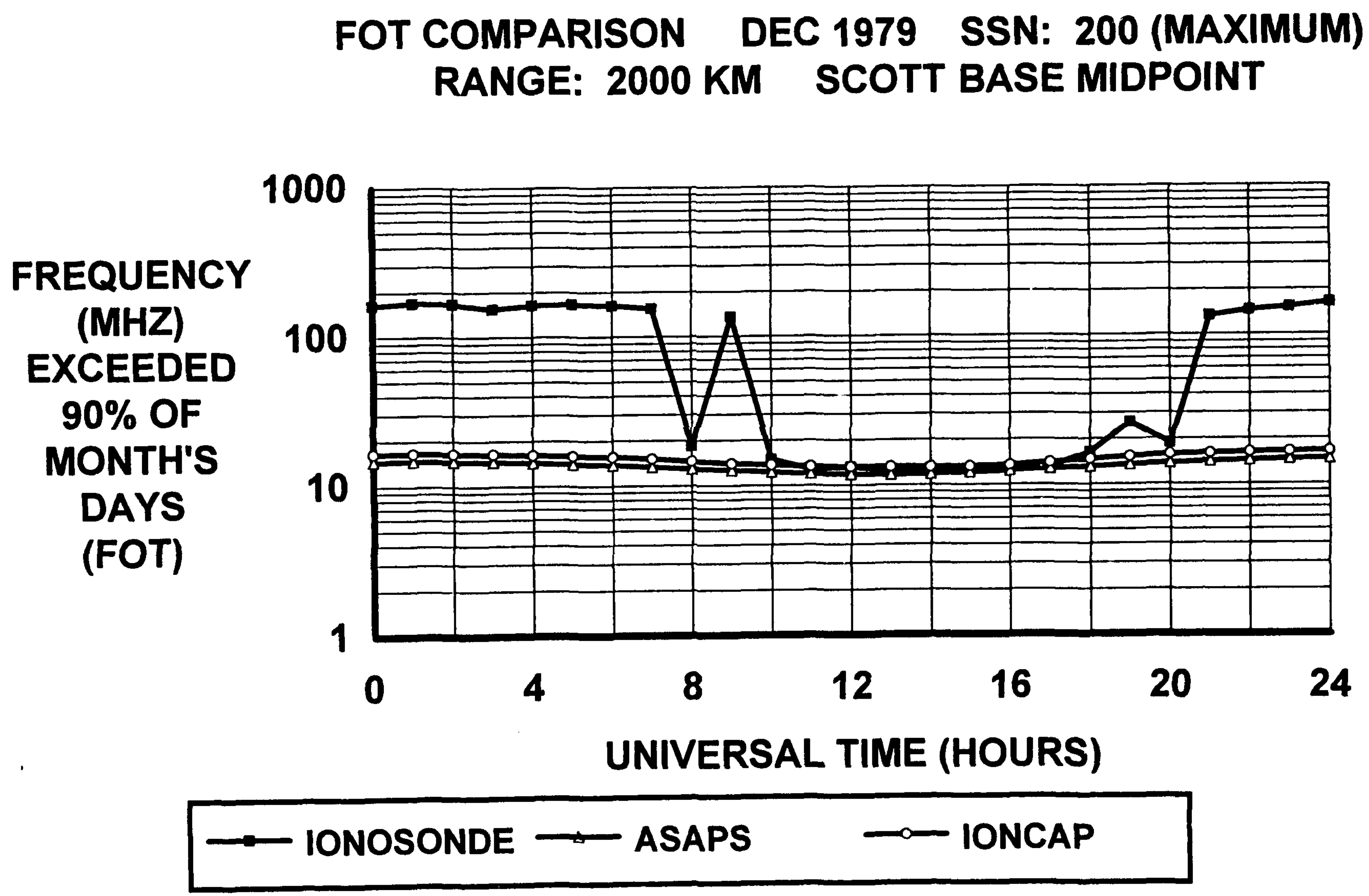
FOT COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT

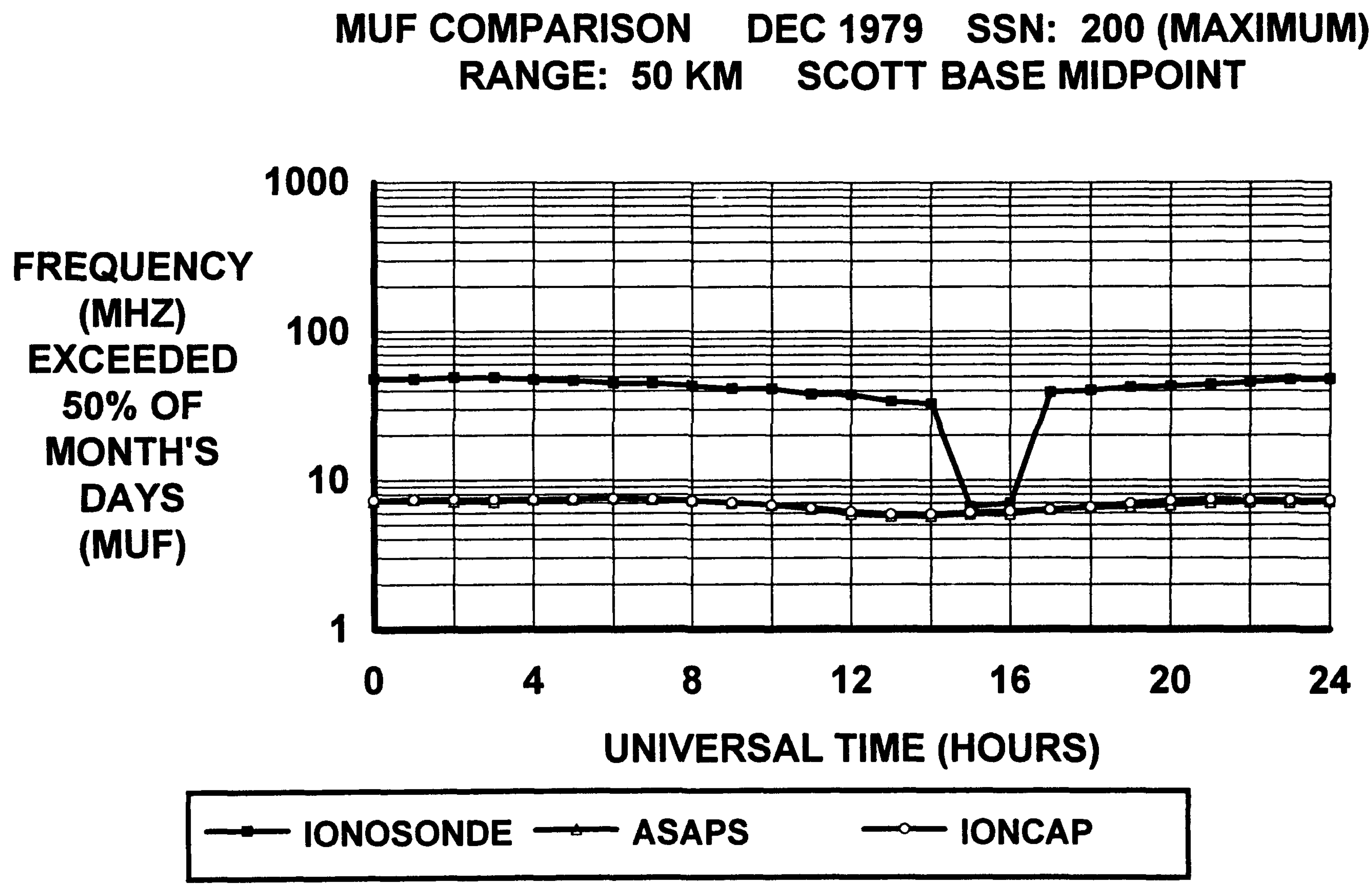


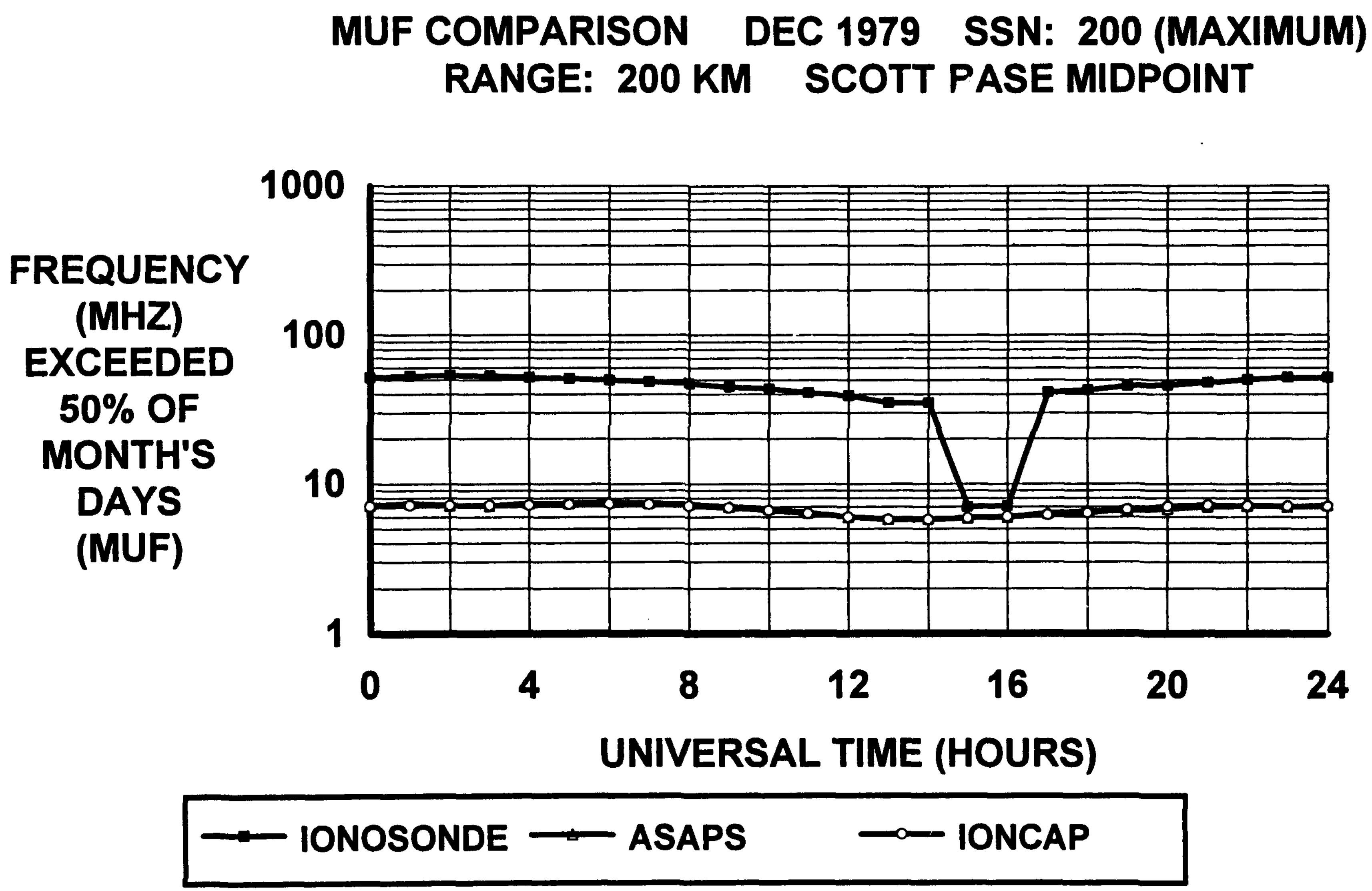

FOT COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
1000
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

FOT COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT

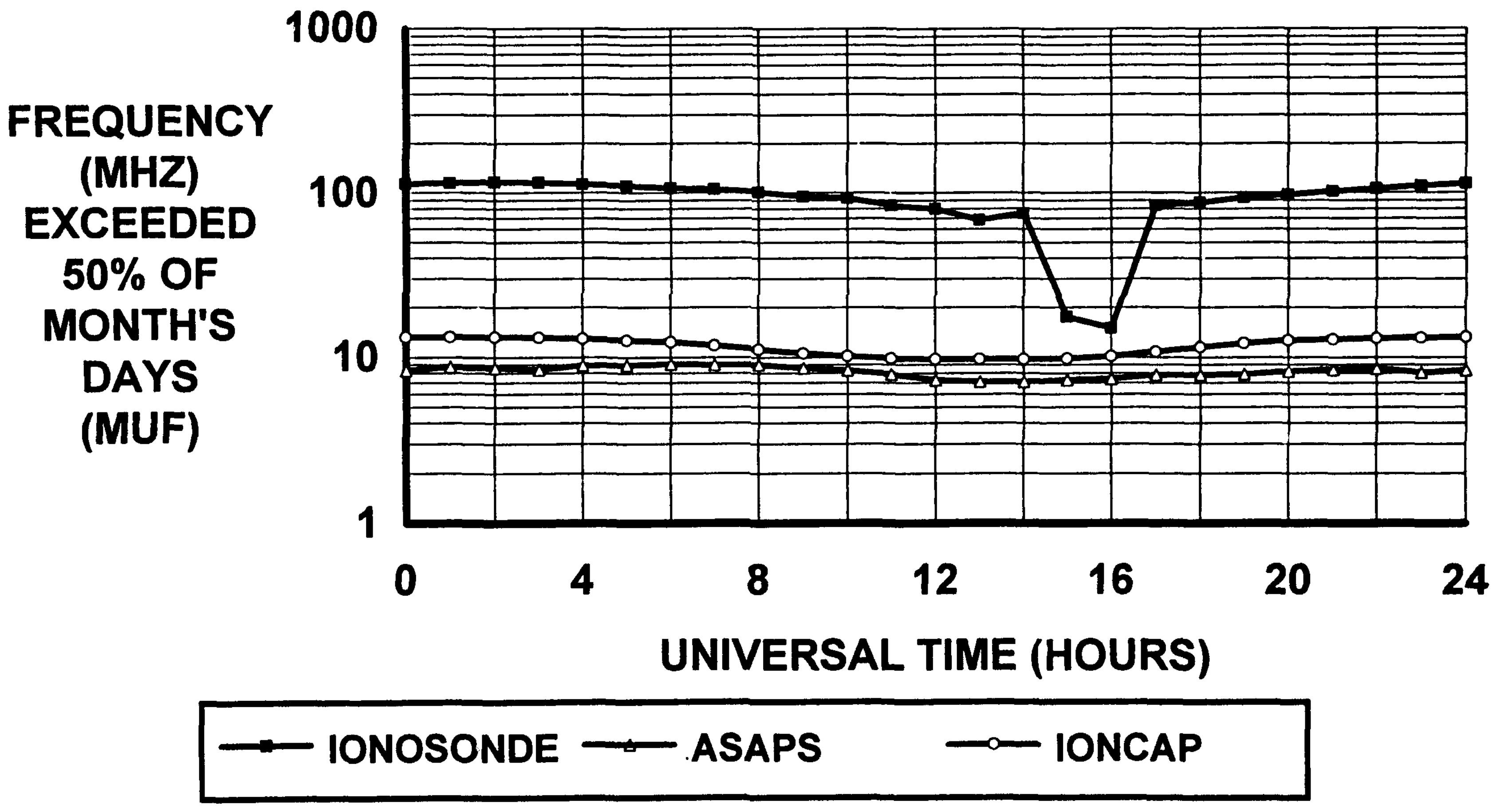



FOT COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 90% OF MONTH'S DAYS (FOT)
1000
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

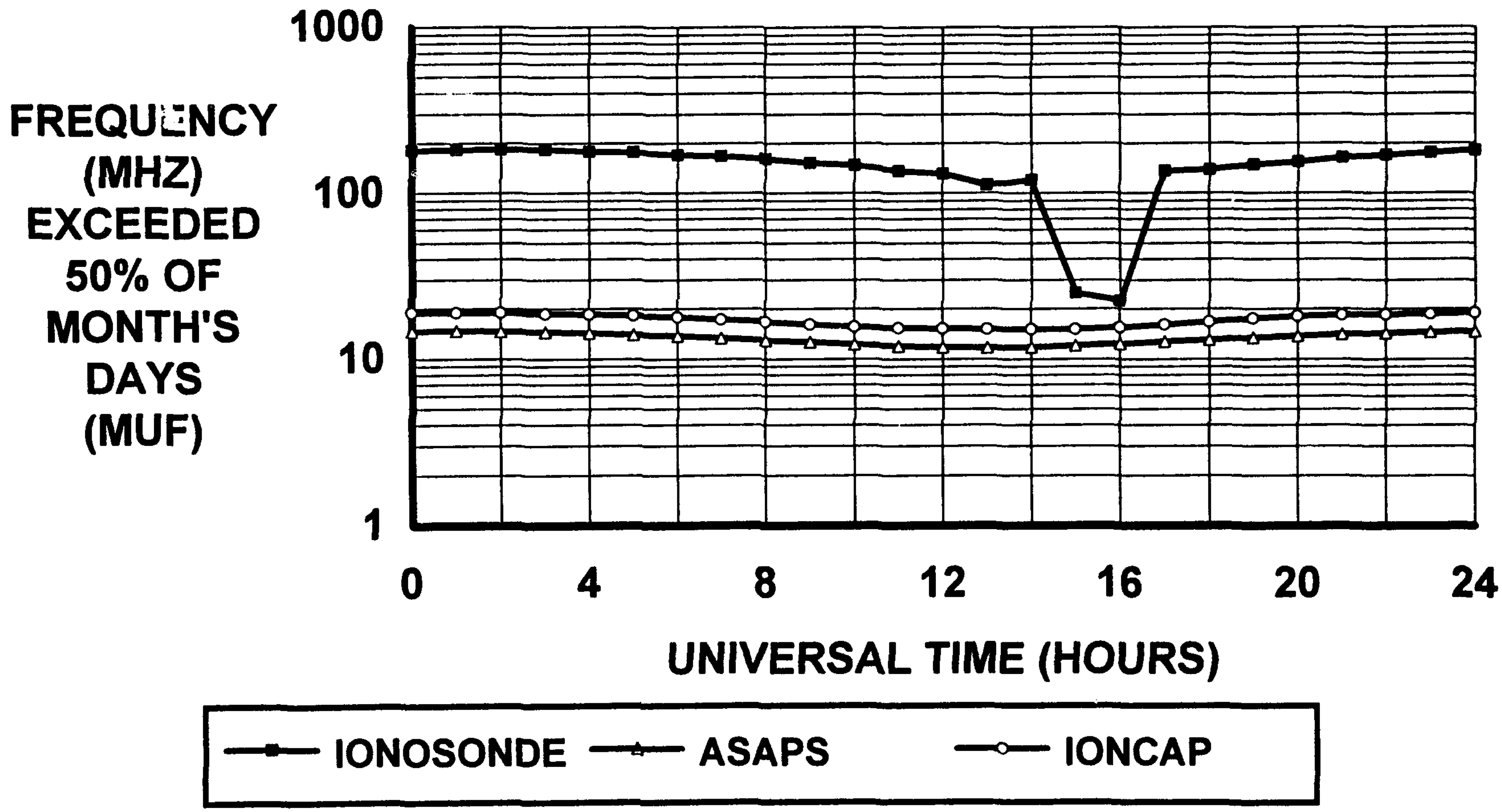

MUF COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
1000
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP


MUF COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 200 KM SCOTT PASE MIDPOINT
FREQUENCY (MHZ) EXCEEDED 50% OF MONTH'S DAYS (MUF)
1000
100
10
1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
IONOSONDE
ASAPS
IONCAP

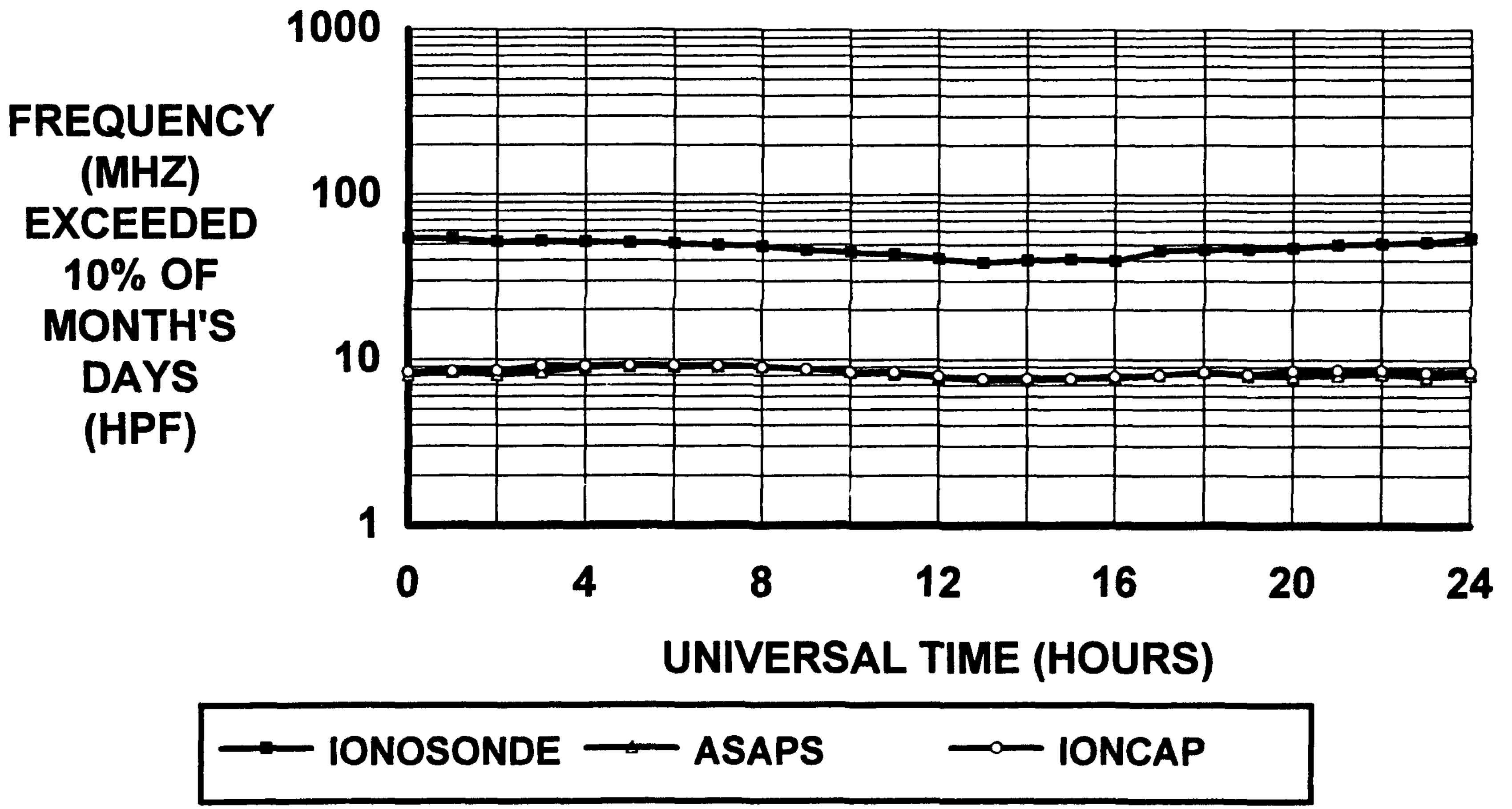
MUF COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT



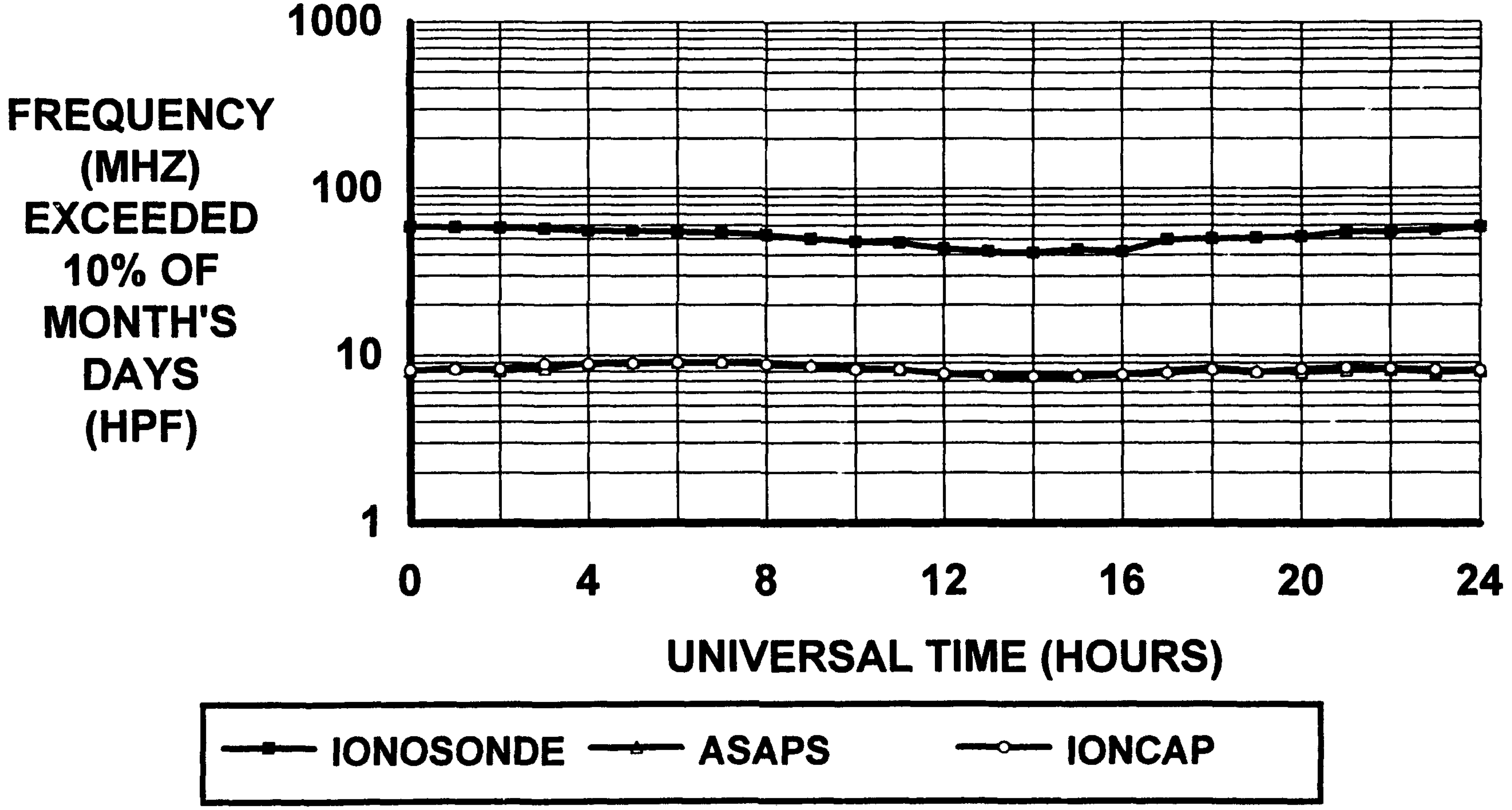
MUF COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT



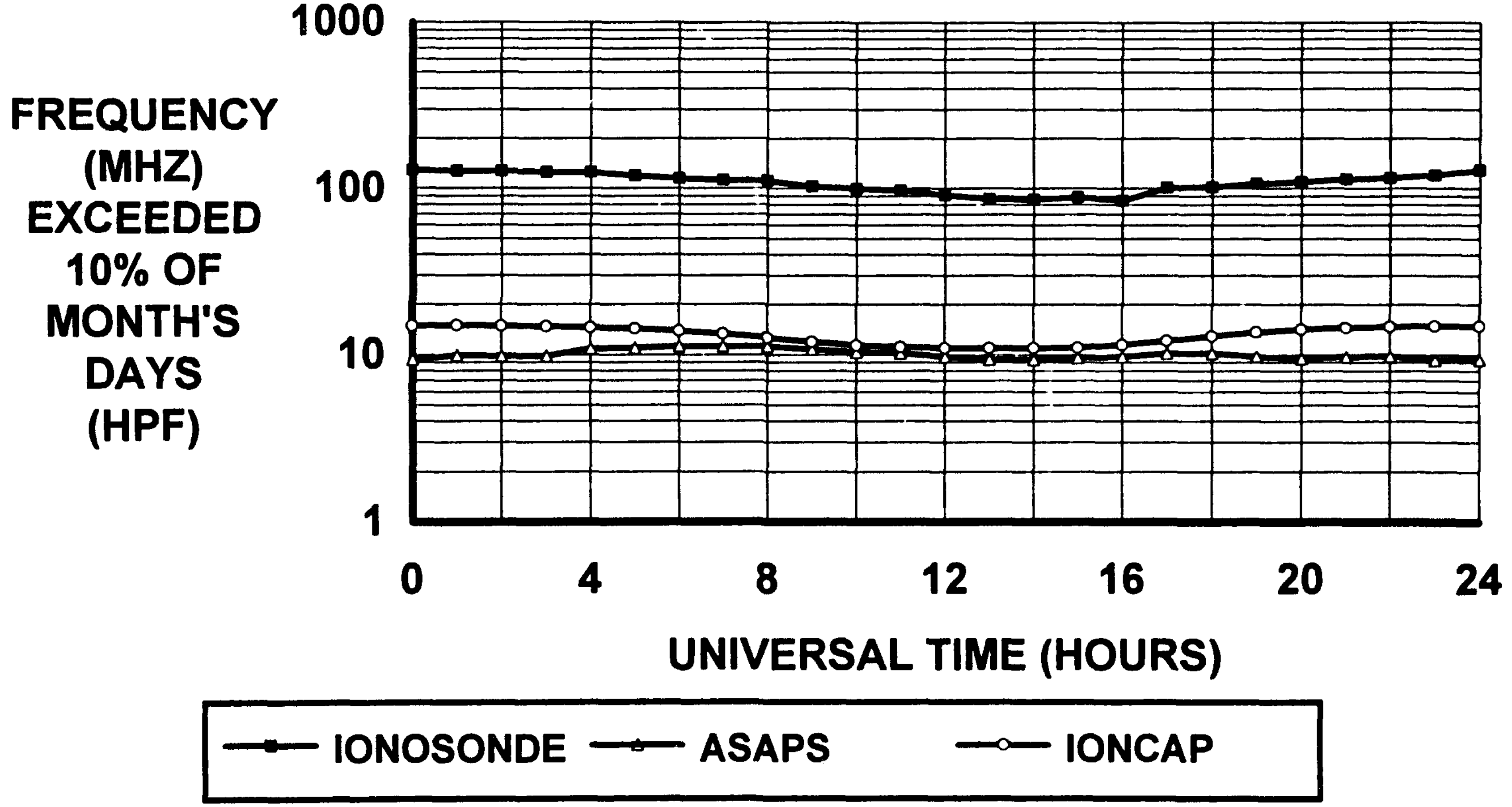
HPF COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 50 KM SCOTT BASE MIDPOINT



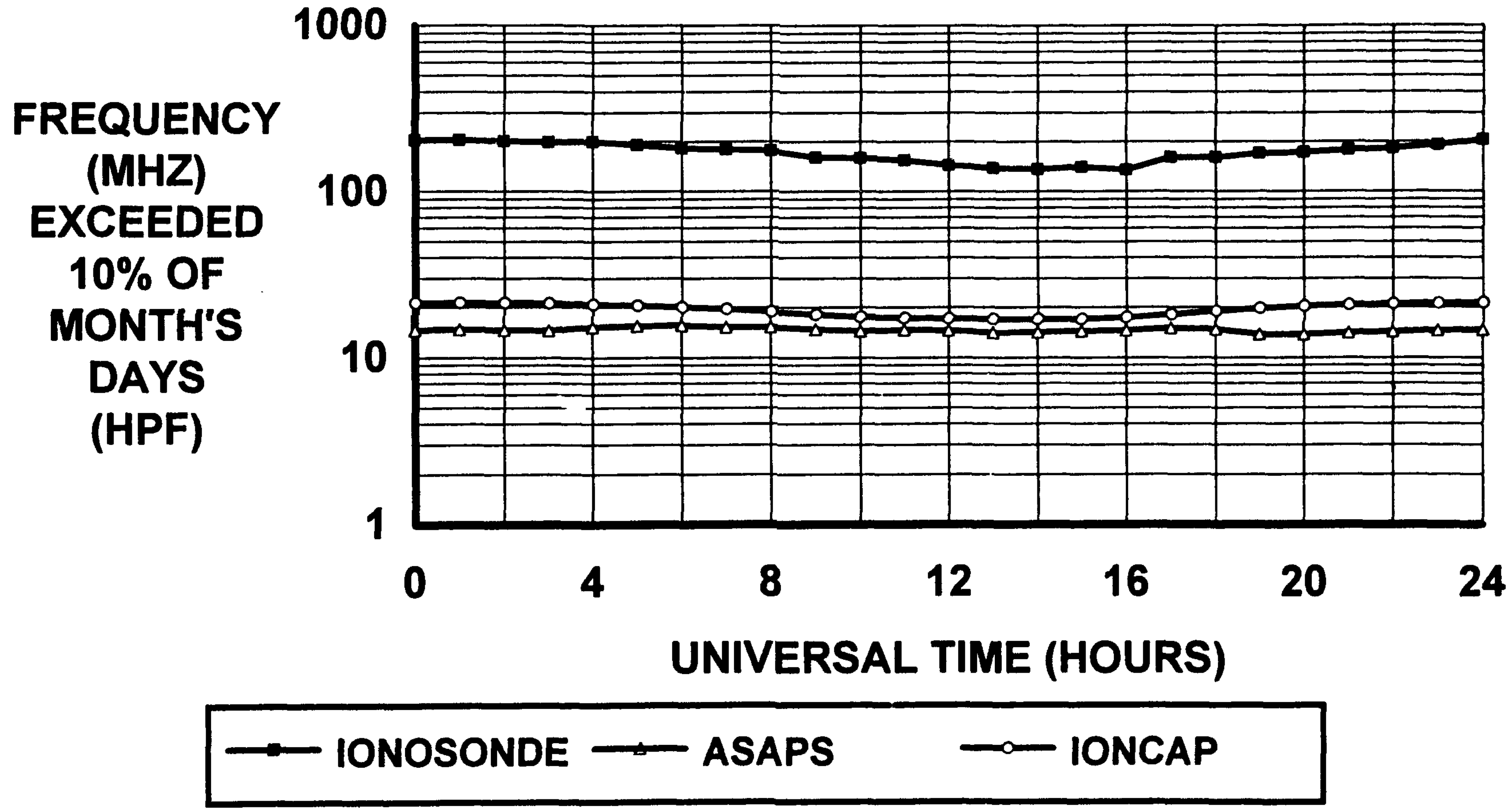
HPF COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 200 KM SCOTT BASE MIDPOINT



HPF COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 1000 KM SCOTT BASE MIDPOINT

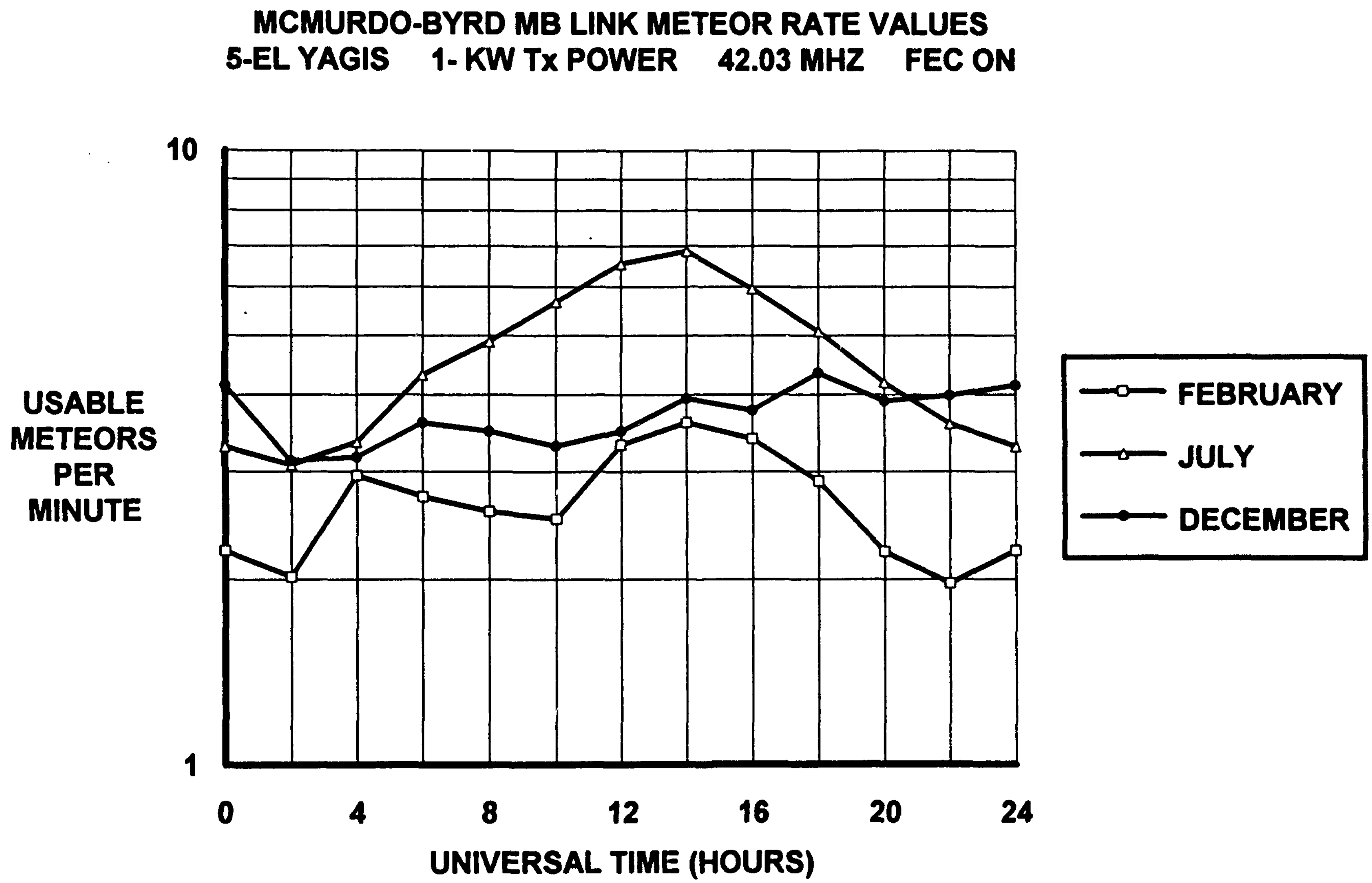


HPF COMPARISON DEC 1979 SSN: 200 (MAXIMUM)
RANGE: 2000 KM SCOTT BASE MIDPOINT

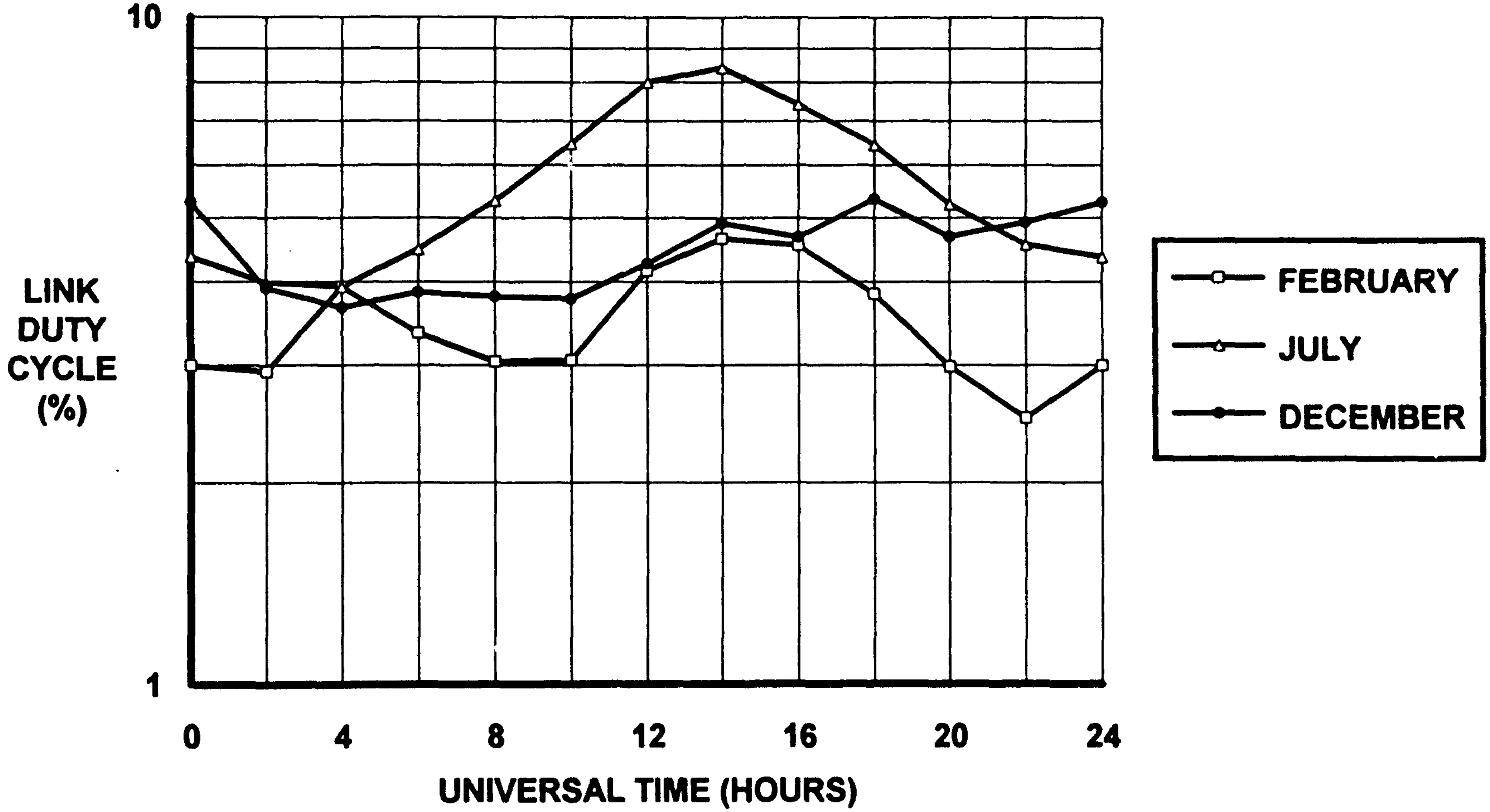


APPENDIX E METEOR BURST LINK PERFORMANCE

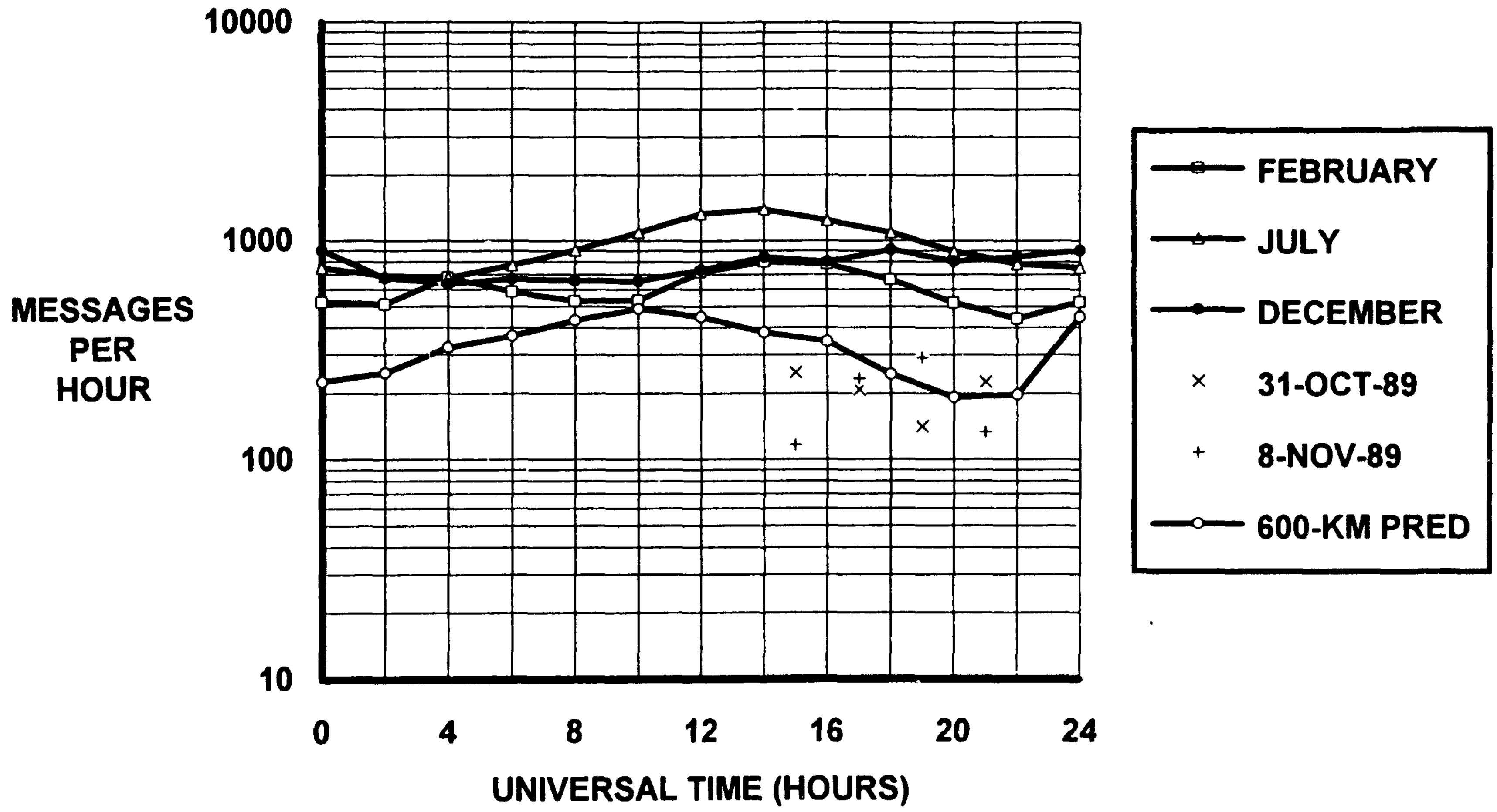
This appendix provides predictions of usable meteor rate (MR), duty cycle (DC), and 120-character message throughput versus time of day. These values are provided for the McMurdo-Byrd link for February, July, and December with corresponding legend entries. In addition, predictions and measurements of link throughput are also provided for a 600-mile CONUS link to provide a validation point. In the plot legends, the "600-KM PRED" refers to the predicted throughput curves while the corresponding measurements for two days in 1989 are depicted in the plot legends as "31-OCT-89" and "8-NOV-89". The plots are presented for both forward error correction "FEC ON" at 42.03 and 48.75 MHz followed by "FEC OFF" for the same frequencies. The MR, DC, and throughput values are provided as separate plots for each case.


MCMURDO-BYRD MB LINK METEOR RATE VALUES
5-EL YAGIS 1- KW Tx POWER 42.03 MHZ FEC ON
10
1
USABLE METEORS PER MINUTE
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
FEBRUARY
JULY
DECEMBER

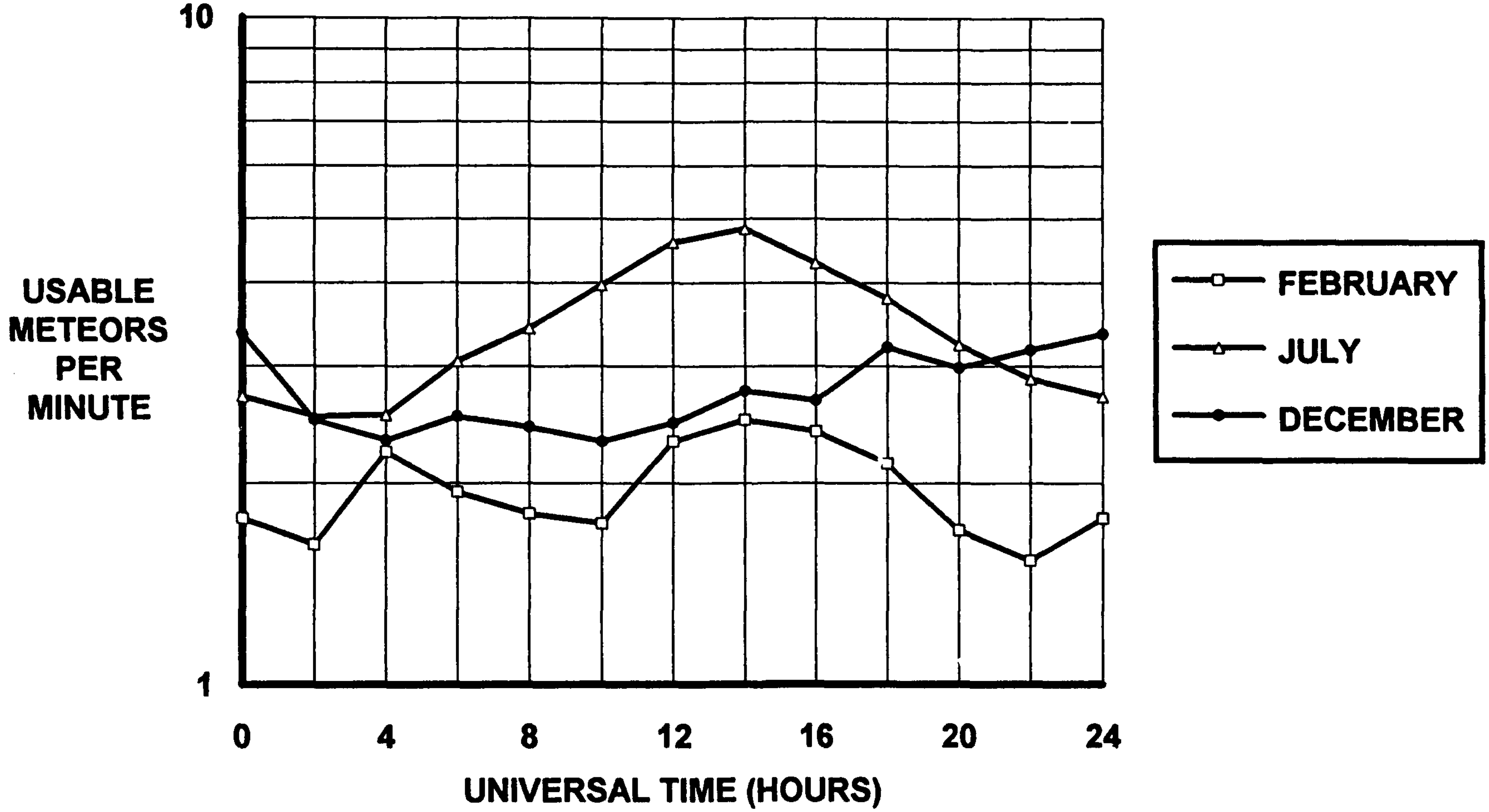
MCMURDO-BYRD MB LINK DUTY CYCLE VALUES
5-EL YAGIS   1- KW Tx POWER   42.03 MHZ   FEC ON

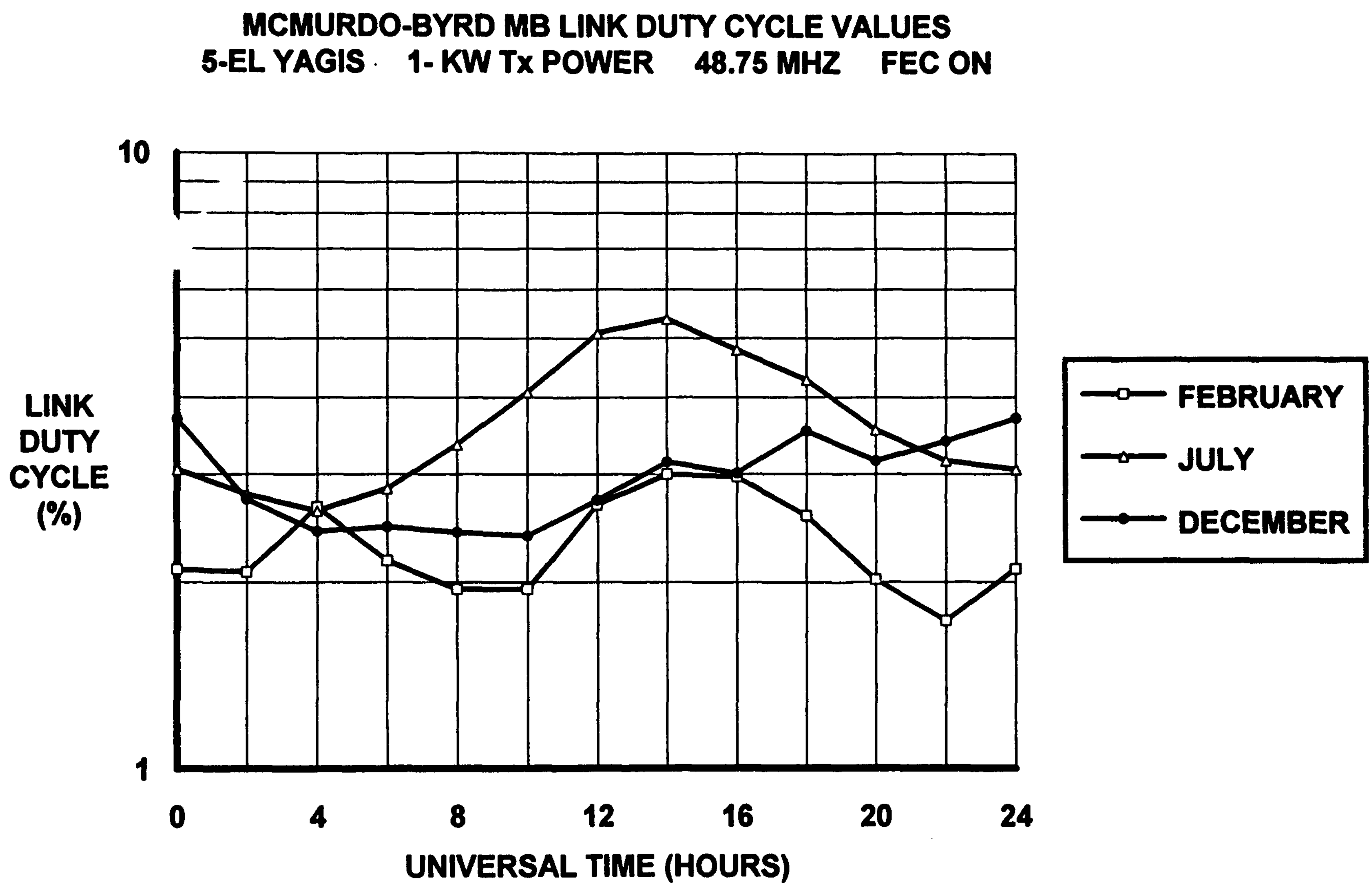


MCMURDO-BYRD MB LINK 120-CHARACTER MESSAGE THROUGHPUT
5-EL YAGIS 1- KW Tx POWER 42.03 MHZ FEC ON

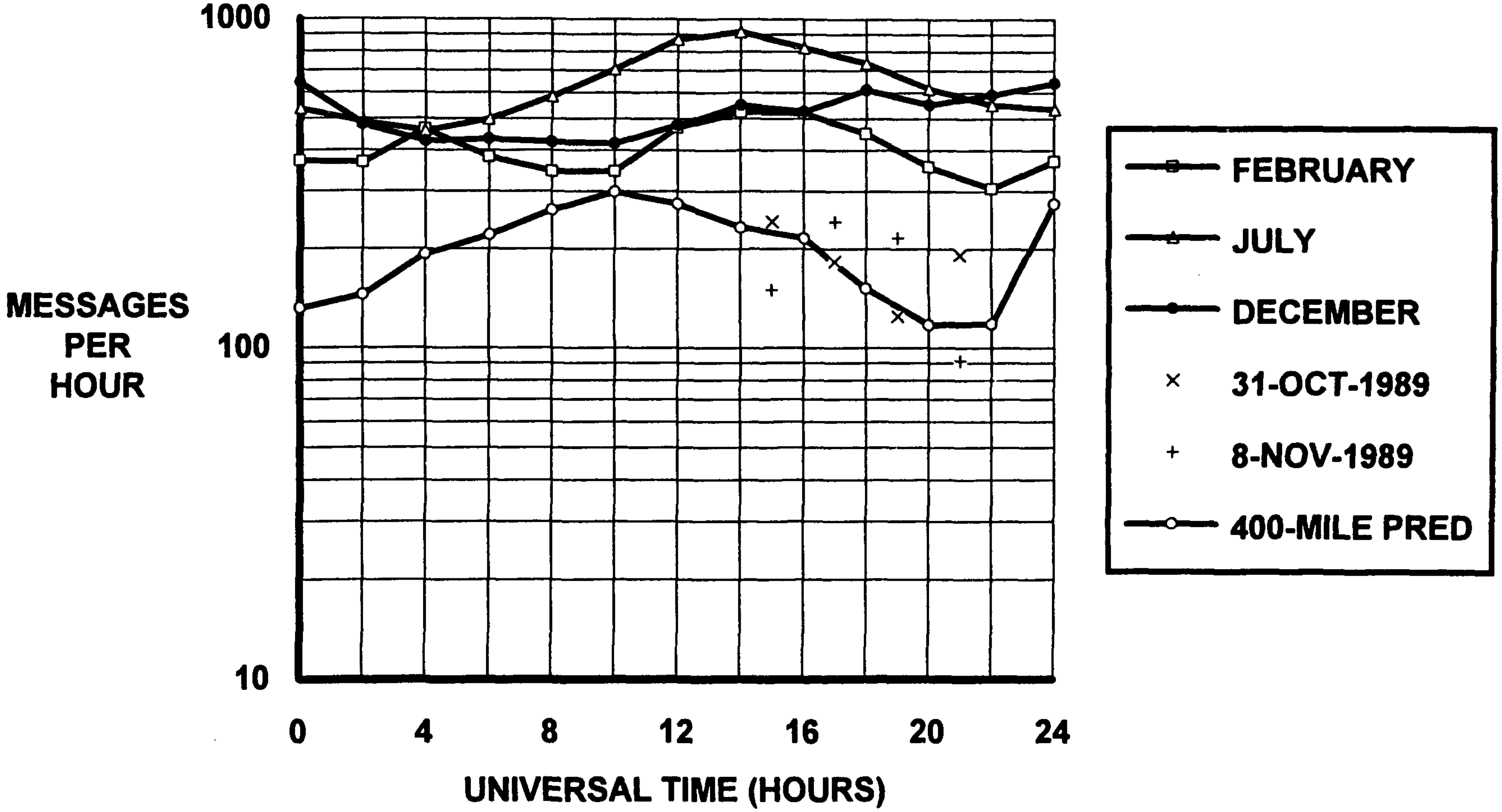


MCMURDO-BYRD MB LINK METEOR RATE VALUES
5-EL YAGIS 1- KW Tx POWER 48.75 MHZ FEC ON

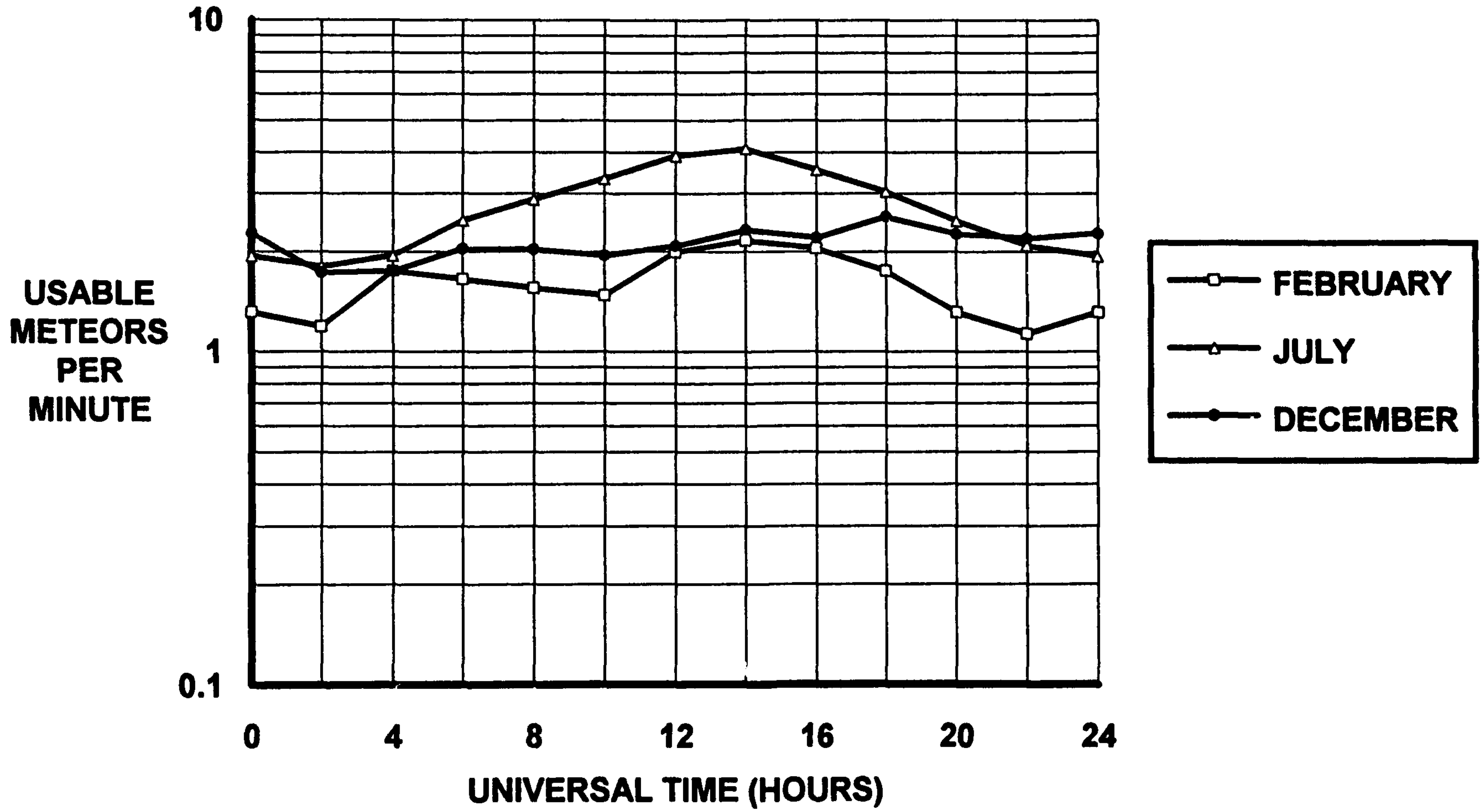


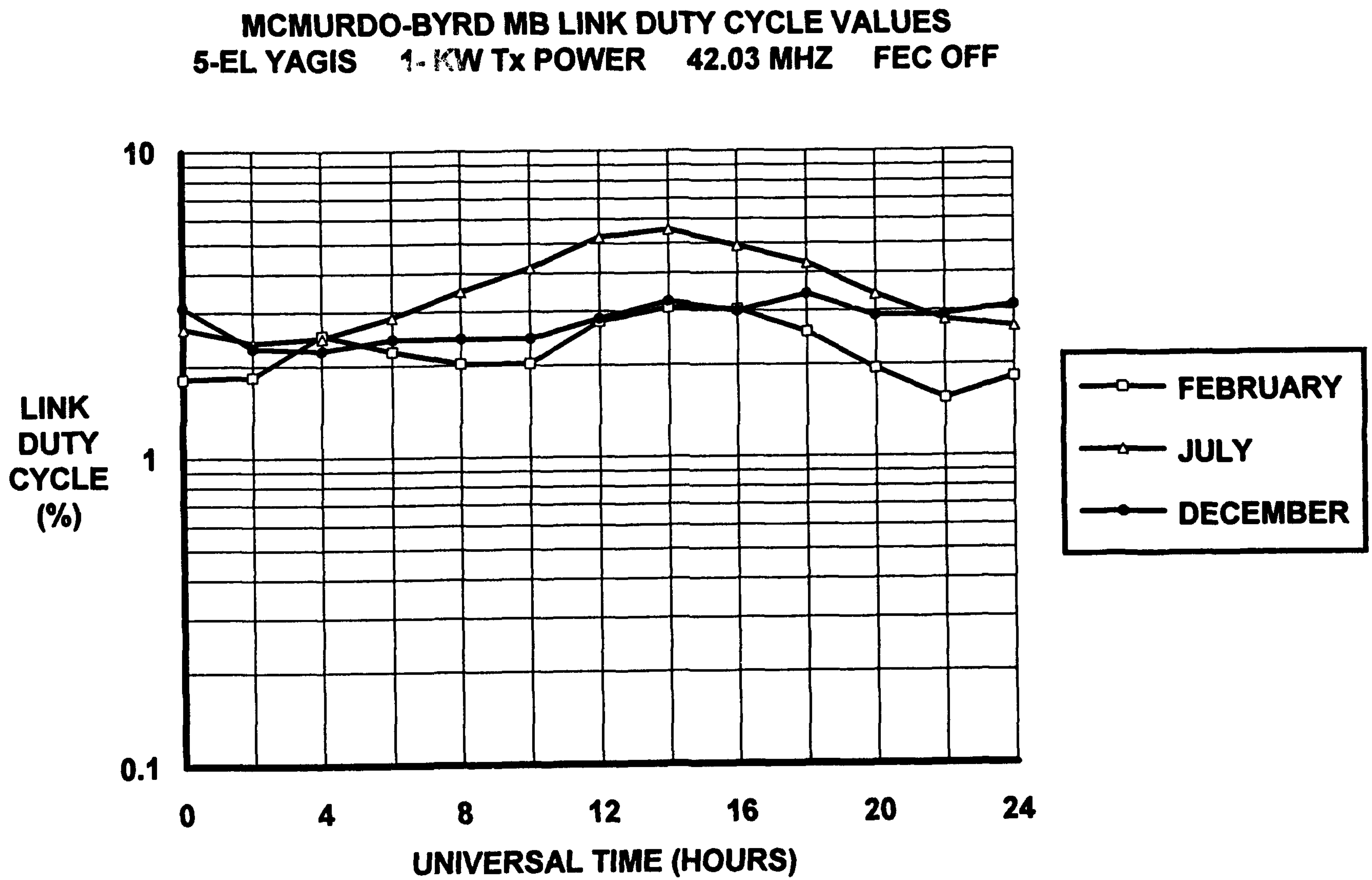

MCMURDO-BYRD MB LINK DUTY CYCLE VALUES
5-EL YAGIS 1- KW Tx POWER 48.75 MHZ FEC ON
10
1
LINK
DUTY
CYCLE
(%)
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
FEBRUARY
JULY
DECEMBER

MCMURDO-BYRD MB LINK 120-CHARACTER MESSAGE THROUGHPUT
5-EL YAGIS   1- KW Tx POWER   48.75 MHZ   FEC ON

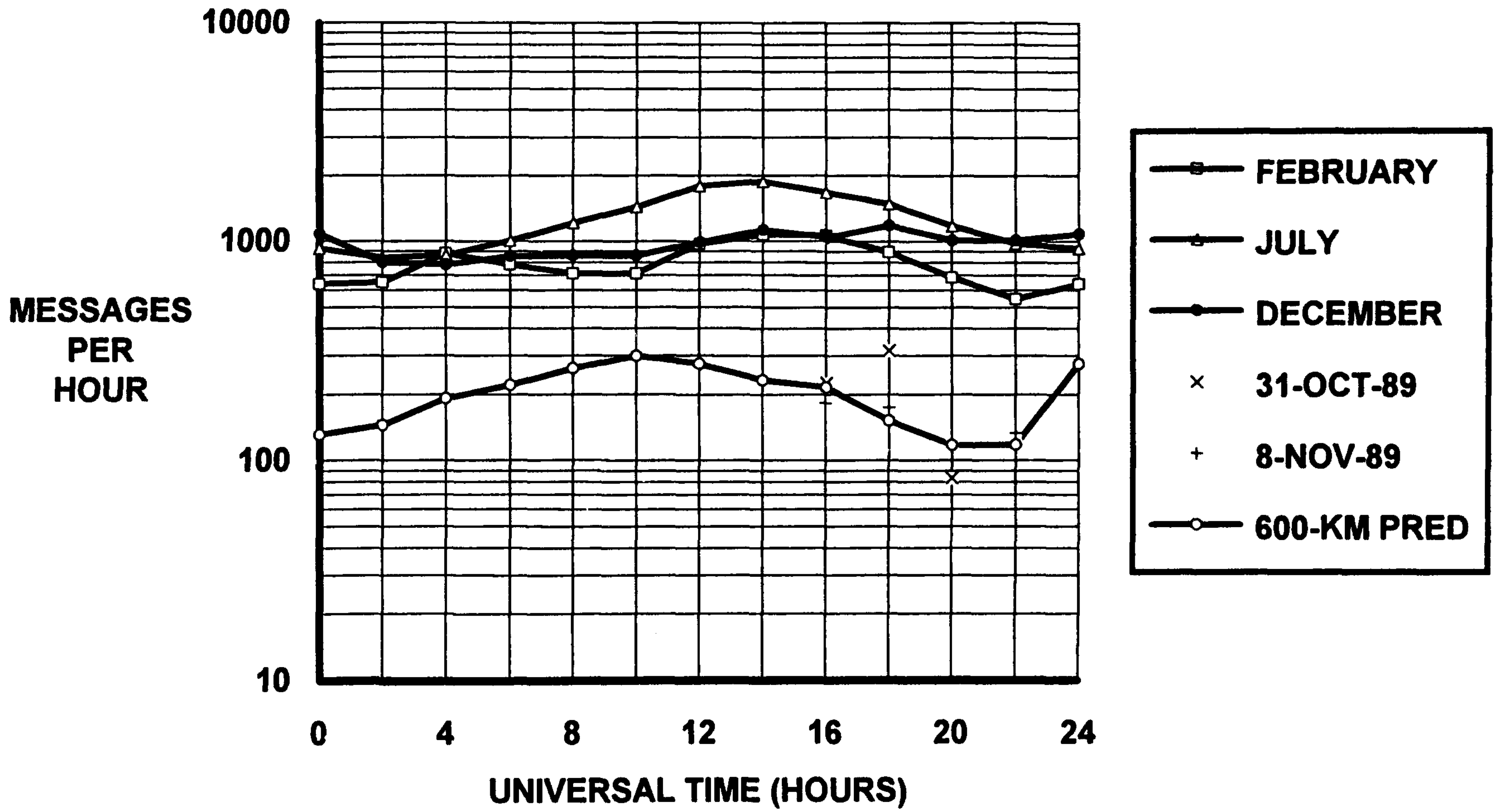


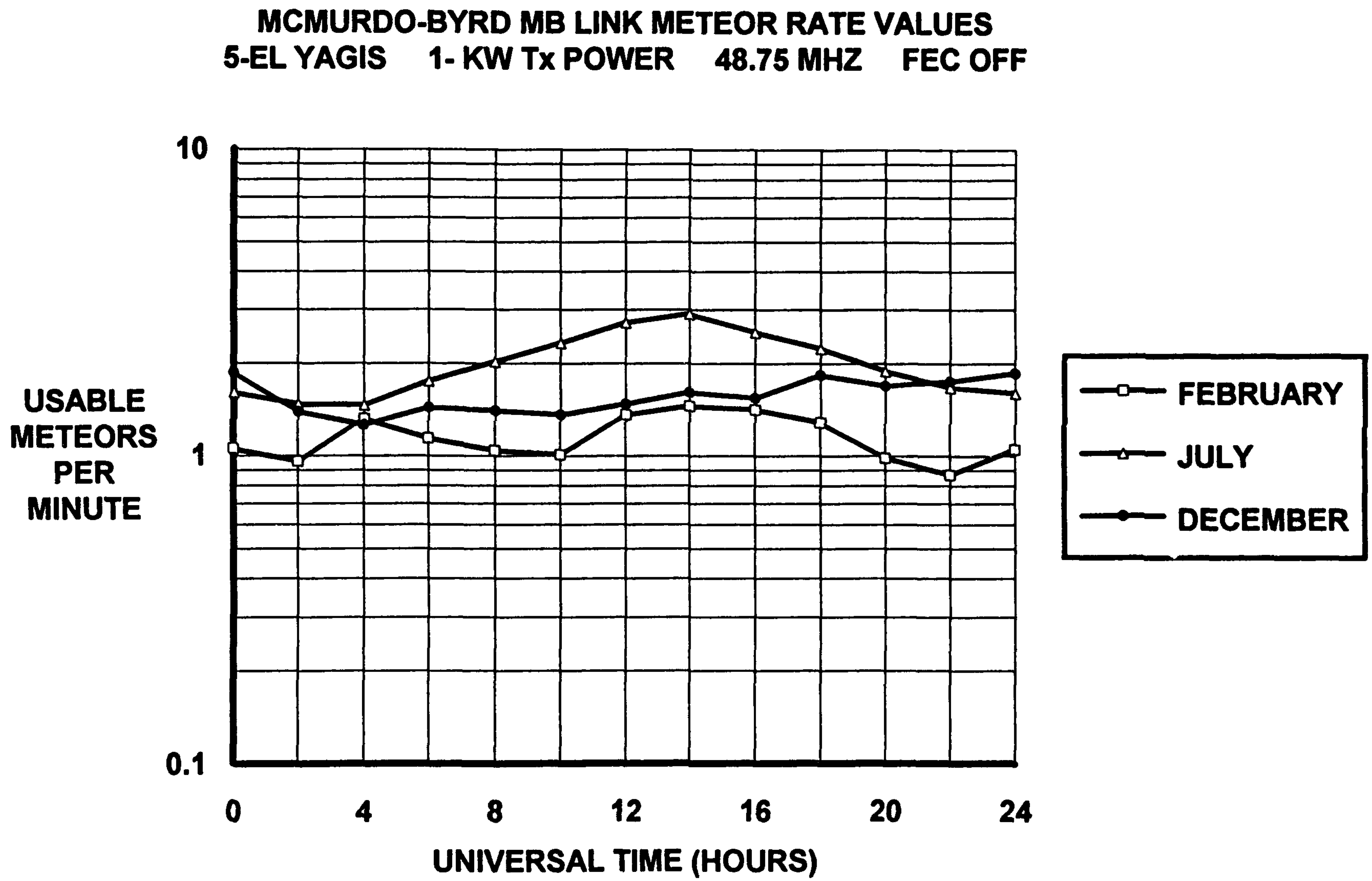
MCMURDO-BYRD MB LINK METEOR RATE VALUES
5-EL YAGIS 1- KW Tx POWER 42.03 MHZ FEC OFF



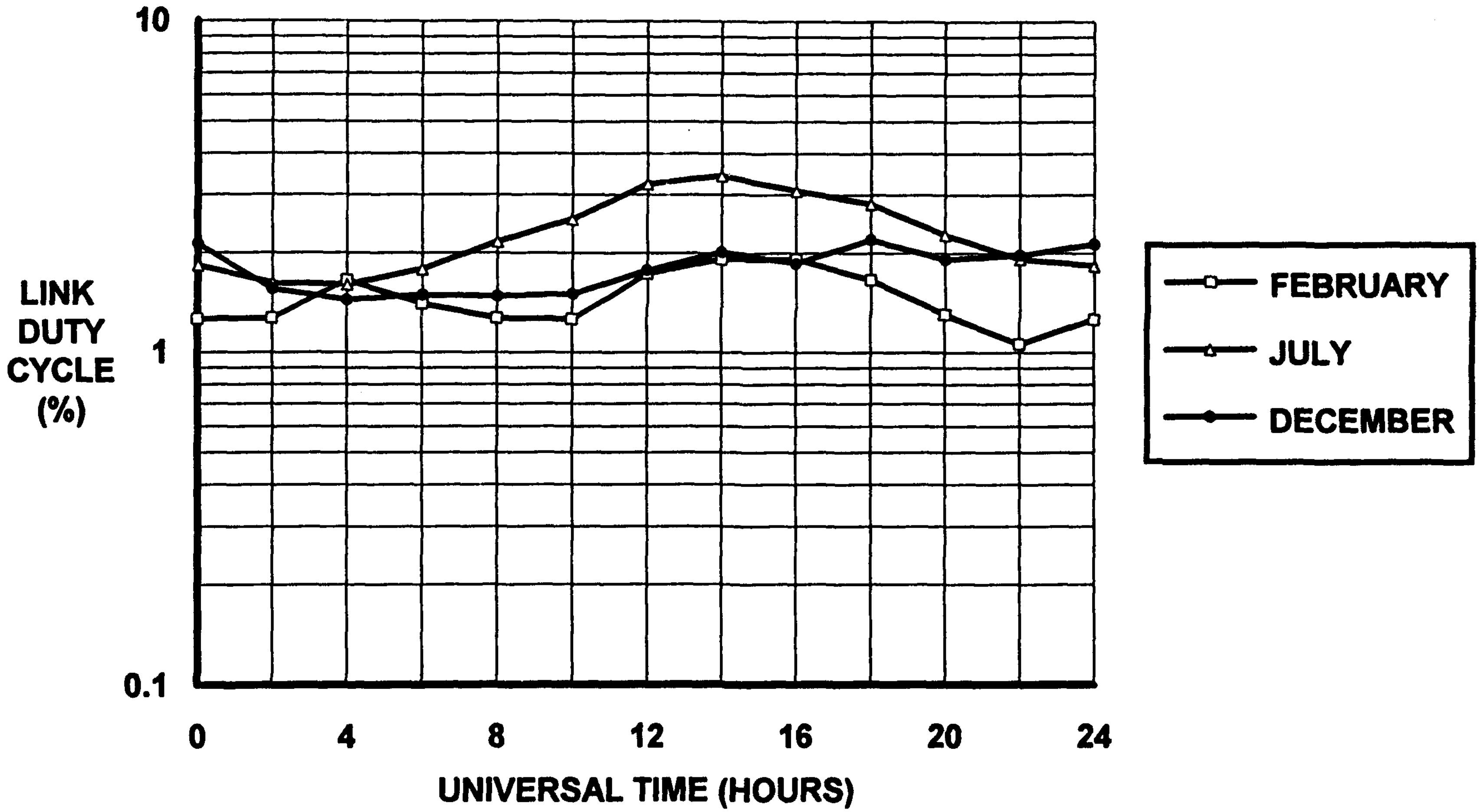

MCMURDO-BYRD MB LINK DUTY CYCLE VALUES
5-EL YAGIS 1- KW Tx POWER 42.03 MHZ FEC OFF
LINK DUTY CYCLE (%)
10
1
0.1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
FEBRUARY
JULY
DECEMBER

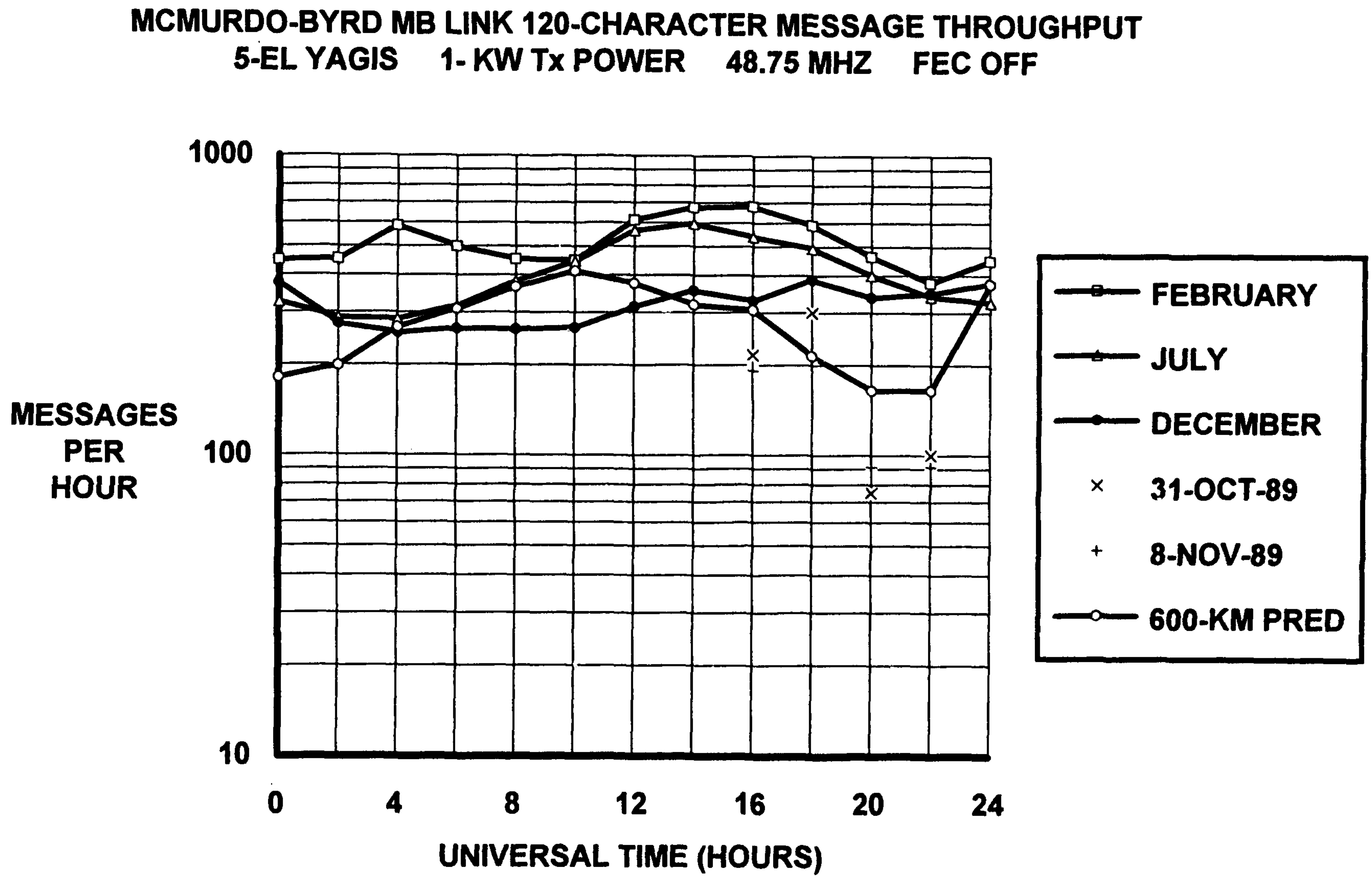
MCMURDO-BYRD MB LINK 120-CHARACTER MESSAGE THROUGHPUT
5-EL YAGIS 1- KW Tx POWER 42.03 MHZ FEC OFF




MCMURDO-BYRD MB LINK METEOR RATE VALUES
5-EL YAGIS 1- KW Tx POWER 48.75 MHZ FEC OFF
USABLE METEORS PER MINUTE
10
1
0.1
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
FEBRUARY
JULY
DECEMBER

MCMURDO-BYRD MB LINK DUTY CYCLE VALUES
5-EL YAGIS 1- KW Tx POWER 48.75 MHZ FEC OFF




MCMURDO-BYRD MB LINK 120-CHARACTER MESSAGE THROUGHPUT
5-EL YAGIS 1- KW Tx POWER 48.75 MHZ FEC OFF
MESSAGES PER HOUR
1000
100
10
0
4
8
12
16
20
24
UNIVERSAL TIME (HOURS)
FEBRUARY
JULY
DECEMBER
31-OCT-89
8-NOV-89
600-KM PRED

APPENDIX F HIGH-ERP METEOR BURST LINK EXPERIMENT

This appendix contains a prepublication copy of a paper to be published in the 1993 Ionospheric Effects Symposium proceedings. It describes the experiment and presents performance estimates.

HIGH-ERP METEOR BURST LINK EXPERIMENT

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ABSTRACT

The Advanced Research Projects Agency (ARPA) has initiated a program to improve the performance of meteor burst (MB) communications in conjunction with the Rome Laboratory, the Naval Electronics Systems Engineering Center (NAVELEXCEN), the Naval Command and Control Ocean Surveillance Center Research, Development, Test, and Evaluation Division (NRAD), the Naval Research Laboratory (NRL), the Phillips Laboratory, and Science Applications International Corporation. The first major effort of this program *is the establishment of the high effective* radiated power (ERP) MB link experiment (HEMBLE) to measure the effectiveness of advanced antenna and modem technologies for meteor burst communications (MBC). The ultimate applications for improved MBC technology are two-fold: over-the-horizon digitized voice, imagery, and message text between fixed sites in a point-to-point configuration, and low probability of intercept (LPI) communications with remote terminals or sensors in a point-to-area configuration. The HEMBLE also provides a measurement tool for the study of ionospheric scatter propagation.

The HEMBLE consists of a 750-mile point-to-point radio link in the eastern US operating in the 40 to 50 MHz band and employing high effective radiated powers (90 dBW) relative to conventional MB link designs (60 dBW). While conventional MB links have employed fixed burst rates below 10 kbps, the high-ERP link test will employ variable burst rates to 128 kbps and fixed burst rates to 512 kbps. The variable burst-rate modem planned for the HEMBLE enables burst transmission rates to be matched to the available channel signal-to-noise ratio (SNR). Maximum throughput is achieved from infrequent transmissions at the peak burst rates (maximum required SNR) produced by the occasional overdense trail-scattered signal. Minimum message waiting time is produced by the lowest burst rates (minimum required SNR) used during the quasi-continuous channel created by the frequent underdense trail-scattered signals. This effort will demonstrate adaptive antenna techniques, advanced MB modem technology, and state-of-the-art source encoding schemes during an on-the-air experiment. Received signal level and phase will be recorded throughout the HEMBLE as well as information transmission performance. This paper describes the HEMBLE measurement objectives to justify the HEMBLE equipment configuration. In addition, a comparison of SAIC METEORLINK computer model predictions with high-ERP MB-link measurements is also provided as well as a forecast of expected HEMBLE performance.

INTRODUCTION

Radiowave scattering from ionized meteor trails has been studied for more than half a century, with direct association of meteoric ionization and VHF radiowave scattering made at Bell Laboratories in the early 1930s [1]. Since that time, meteor radars have employed the scattering from ionized meteor trails to do the following: (1) measure meteor velocities [2], (2) determine the radiant densities of stream and sporadic meteors [3], and (3) estimate the speed and direction of upper atmospheric winds [4]. Experimental forward meteor scatter links were employed to analyze the propagation phenomena from a communications perspective by focusing on the availability of trail-scattered signals [5] and the available channel bandwidth [6]. Pioneer MB link experiments were conducted by the National Bureau of Standards [7], the Stanford Research Institute [8], Hughes Aircraft [9], the Boeing Company [10], and the Georgia Institute of Technology [11]. The most well-known of these experimental systems were JANET [12] (Defense Research Board of Canada) and COMET [13] (SHAPE Technical Center), developed as a NATO communication system. Significant advances in meteor science and engineering have also been achieved in Russia, most notably by researchers at the Kazan State University (KSU). Their work, published in a yearly periodical devoted to meteor scatter since 1963 [14], begins with channel characterization and modeling efforts and proceeds to the development of optimum MB communication system design. Their work continues to the present day, with the recent announcement that their MB time synchronization system has achieved a 1-ns error after 2-hour link operation [15].

US Government meteor scatter research in recent years has been performed primarily by the Philips Laboratory (PL), formerly the Air Force Geophysics Laboratory (AFGL). The PL operates the High-Latitude Meteor Burst Test Bed originally established by the Rome Air Development Center (RADC, now the Rome Laboratory) in Greenland between Sondrestrom Air Force Base (AFB) and Thule AFB [16]. Since that time, the test bed has employed five signal frequencies from 35 to 147 MHz with 1-kW transmit power and a well-calibrated received signal recording system. Post-processing software has been developed to distinguish between meteoric and nonmeteoric propagation events as well as to classify trail-scatter events into underdense, overdense, and nonspecular overdense behavior types [17]. These links have provided invaluable data relating the performance of VHF meteor scatter propagation and the corresponding background noise environment at high latitude caused by sudden ionospheric disturbances (SIDs), such as high D-region absorption and flux-induced noise enhancement [18]. In addition, they have also provided valuable validation data for the development of accurate MB computer prediction models [19].

With the advent of effective satellite communication systems, the growth of redundant telephone services, and the technological sophistication required to efficiently utilize short-lived trail-scatter signals, meteor scatter research waned in the West through the 1960s. Nevertheless, several appropriate applications emerged for MBC. The US Department of Agriculture's Soil Conservation Service Division developed the SNOTEL [20] system to monitor snowpack for runoff management using over 650 remote solar-powered weather stations outfitted with MB telemetry. The North American Air Defense Command (NORAD) installed MB communication links to provide satellite telemetry backup in Alaska as well as interbase communications within the continental US [21]. An international market for MBC has developed due to the significant economic and political costs of reliance on externally-controlled satellite systems. International government and civilian users of MBC for message traffic or telemetry include the

Peoples Republic of China [22], Egypt, and Brazil. Much of the system design expertise, terminal equipment, and antennas for these applications were provided by the Meteor Communications Corporation (MCC) of Kent, Washington.

Most MB communication links operate with moderate gain (e.g., single 5-element Yagi) antennas and transmit powers ranging from 100 W to 10 kW. Practical high-power VHF communication circuits began employing meteoric propagation in the early 1950s with the installation of the North Atlantic VHF Ionospheric Scatter System [23], consisting of a string of ionoscatter links interconnecting Massachusetts to England via Halifax (Canada), Sondresromfjord (Greenland), Thule (Greenland), and Iceland. In general, these ionoscatter circuits employed D- and E-layer scatter as well as meteor scatter. They operated primarily in the 30- to 50-MHz band and used 20- to 25-dBi antenna gains with 10- to 50-kW transmit powers. These circuits were capable of providing continuous signals for 99% of the year at ranges up to 1200 miles. The ionoscatter signal was frequently enhanced by intermittent trail-scatter events, which offered significantly increased channel bandwidth due to the relatively small size of the trail scatterer as compared to the relevant D- and E-region scattering volume. The *significant variations in received* signal level (RSL) suggested that a variable data rate would optimize throughput by matching the transmission, or burst, rate to the short-term signal-to-noise ratio (SNR) [24] as depicted in Fig. 1. This early work also suggested the use of high-gain fixed or steerable antenna beams to focus on the usable trail-scattering common volume to either side of the link Great Circle path (GCP). The use of steerable beams is depicted for a north-south link in Fig. 2 [25]. Off-GCP focusing was believed to increase channel bandwidth by avoiding D- and E-region ionoscatter. It must be emphasized that the wideband meteoric component is capable of coherence bandwidths in excess of 1 MHz [26].

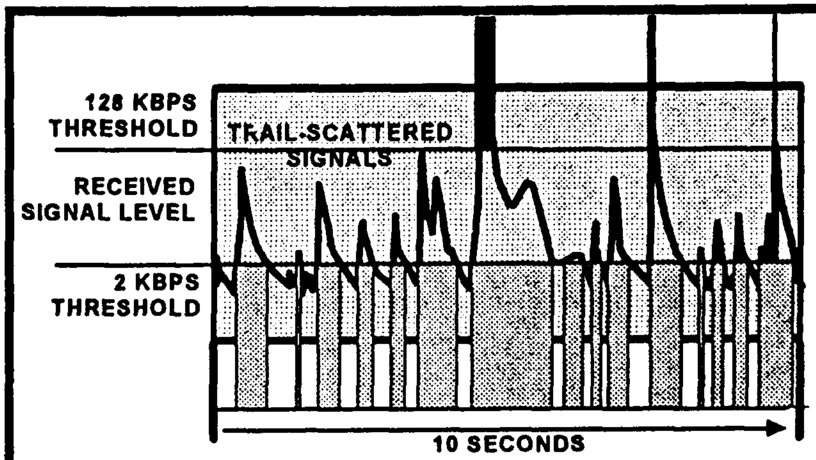

Fig. 1 Variable Burst Rate

In 1991, MCC demonstrated a 580-mile MBC link between Bozemen, Montana and Shelton, Washington [27]. This link combined the use of a higher ERP than used for typical MB links with the variable burst-rate modem technology available in the 6560 Advanced Meteor Burst Master Station built by MCC. This link used a single 10-kW high power amplifier (HPA) and a receive-only fixed-multibeam antenna array. This array employs four 7-element Yagis whose outputs are split and phased using a Butler matrix to present simultaneous inputs to each of the four 6560 receivers. Each input represents a different antenna beam pointed to optimally illuminate the usable off-GCP MB-link common volume. A 6560 processor selects the strongest RSL

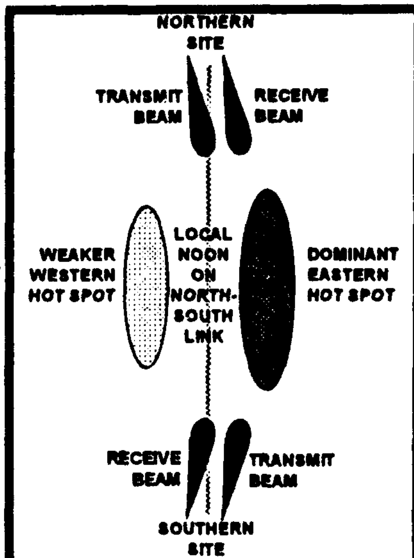

Fig. 2 Hot-Spot Migration

corresponding to one of the four antenna beams. Variable transmission burst rates are based on SNR measurements fed back from the distant terminal. The combination of variable burst-rate transmissions with fixed-multibeam antenna arrays represents an innovation in MBC technology. The high-ERP link, achieved with the combination of 10-kW transmit power and high-gain arrays, assures a significant rate of usable trail-scattered signals whose SNR-values support burst rates in excess of 100 kbps. The minimum hourly-averaged information throughput measured on this link in April, 1992 was 2000 bps, with average daily throughput of 4000 bps [28].

The Advanced Research Projects Agency (ARPA) has embarked on a theoretical and experimental program to integrate and test existing meteor burst communications technology with the purpose of demonstrating state-of-the-art performance to US Government agencies (USGAs) and other users. ARPA coordinates HEMBLE activities through Science Applications International Corporation (SAIC), which serves as the systems engineer. ARPA's USG engineering agents include the Rome Laboratory, the Naval Electronics Engineering Center (NAVELEXCEN Charleston), the Naval Command and Control Ocean Surveillance Center Research, Development, Test, and Evaluation Division (NRAD), the Naval Research Laboratory (NRL), and the Phillips Laboratory. This effort provides Government-sponsored verification and enhancement of the recent achievements in high-throughput MB digital communications performed by MCC. These performance results will be used to validate suitable applications for MBC, such as point-to-point digitized voice, slow-scan video, imagery, and text message traffic between large fixed sites. In addition, the HEMBLF demonstrates low-rate telemetry between a fixed site and a disadvantaged terminal (restrictive size and low-power constraints). Improved MBC technology provides a viable alternative to automatic link establishment (ALE) HF radio for path lengths below 2000 km and as a backup, alternative, or supplement for SATCOM links. Beyond this objective, the ARPA MB program investigates increased burst transmission rates, antenna array beamforming techniques, and source encoding schemes not yet demonstrated on the MB channel. Recently, Science Applications International Corporation (SAIC) performed computer modeling of the high-ERP link to verify the expected performance improvement, design the HEMBLE antenna arrays, and specify HEMBLE hardware and software components [29].

THE HIGH-ERP MB LINK EXPERIMENT (HEMBLE)

Site Survey

The HEMBLE is operated between the Verona Test Annex of the Rome Laboratory, Verona, New York (43°9'0" N, 75°37'9" W) and NAVELEXCEN, Charleston, South Carolina (32°55'18" N, 79°58'4" W). The geographic bearing from Verona to Charleston is about 200 degrees east of true north, so the link is oriented nearly north-south with a total path length of about 750 miles. (1200 km). The terrain is flat and smooth at both sites. The Verona site faces an expanse of wetlands at about 450 ft above sea level (asl). The foreground of the Charleston site, located within ten miles of the Atlantic coast, consists of marshlands at about 50 ft asl.

Noise measurements spanning the 40 to 50 MHz band chosen for the HEMBLE were conducted at both Charleston and Verona to verify that the chosen HEMBLE sites were electromagnetically quiet. Fig. 3 is a comparison of SAIC-predicted Galactic noise

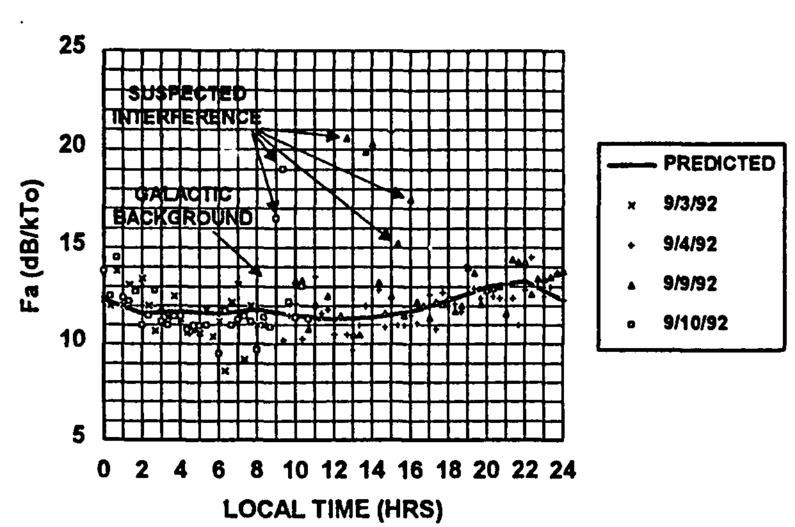

Fig. 3 Charleston Galactic Noise at 46.65 MHz

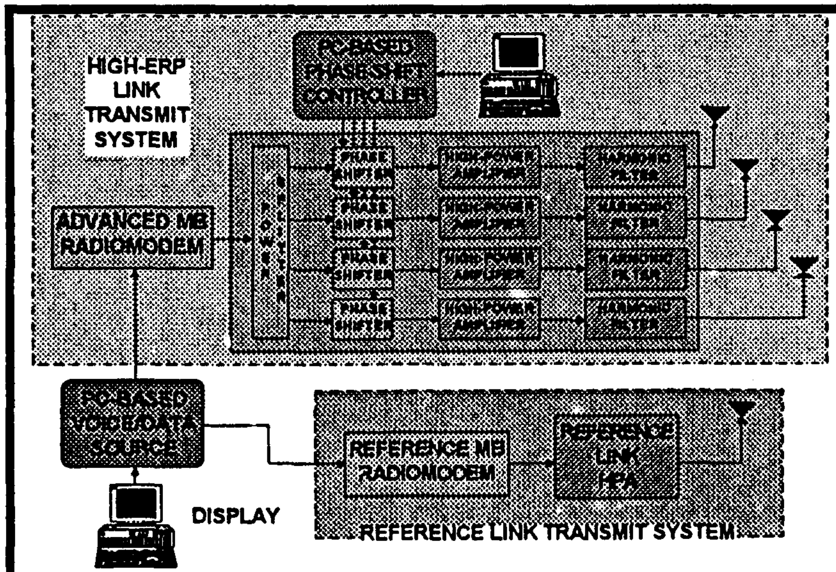

Fig. 4 HEMBLE Transmit Systems

levels for a dipole antenna elevated to one-wavelength height above ground and the corresponding measurements at the Charleston site. The SAIC predictions employed a digitized Galactic map of Galactic radio-noise sources and integrated the NEC-generated dipole antenna-gain pattern over this noise map. The agreement between prediction and measurement shown in the figure suggested that the dominant noise source was of Galactic origin, the lowest background noise possible in the 40- to 50-MHz band, although occasional manmade interference was also observed.

Transmit Systems

High-ERP Link. The HEMBLE transmit system, identical at both Verona and Charleston, consists of independent high-ERP and reference link systems as shown in Fig. 4. The high-ERP system employs the MCC-6560 Advanced Master Station, a digitally-controlled 4.8-kW HPA, and an array of eight 7-element Yagis. The MCC-6560 is an off-the-shelf unit built and upgraded by MCC to operate at variable burst transmission rates between 2 and 128 kbps. The variable burst transmission rate automatically adjusts the SNR to maximize burst throughput (highest rates) while minimizing burst interoccurrence times (lowest rates). The 6560 employs optional convolutional forward error correction (FEC) with Viterbi decoding and an infinite stack of messages queued for transmission. This last feature assures that all available MB channel time is employed for an accurate measure of high-ERP link performance. A second modem, developed by ITT for the Rome Laboratory, will be interchanged with the 6560. The ITT radiomodem does not provide burst-variable operation, but it permits fixed burst rate operation up to 512 kbps while employing a Reed-Solomon FEC algorithm. Both the 6560 and the ITT modem operate in the full-duplex mode, although the 6560 also functions in the

half-duplex mode when employed with compatible MCC remote terminals.

The HPA provides four independently-phased output signals each at a maximum power of 1.2 kW. As shown in Fig. 4, the radiomodem input is split into four independent paths. Each path contains a digitally-controlled broadband phase shifter so the four inputs to the transmit antenna array can be independently phased. As a result, the array's main beam may be steered to point at the most active hot spot versus time of day. A PC controller sheltered with the amplifier periodically updates the relative phase values to achieve diurnal hot-spot tracking. These values are determined either by phase measurement or computer prediction.

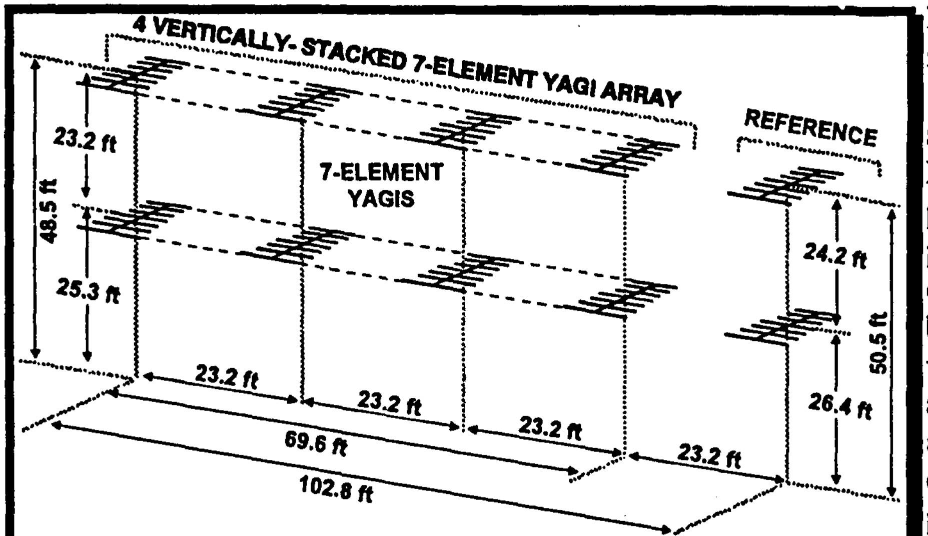

Fig. 5 HEMBLE Antenna Arrays

Each of the four amplifiers feeds a pair of vertically-stacked 7-element horizontally-polarized Yagi antennas equiphased from a common feed point. The phase center, located halfway between the two Yagis, was positioned at a height of 7/4 wavelengths above ground. This height was shown by computer modeling to yield the maximum usable meteor-rate (MR) and duty-cycle (DC) values for both the high-ERP and reference links. The resulting 56-element array is depicted in Fig. 5. Fig. 6 shows the azimuth and elevation patterns for 0° phasing of all amplifier branches as computed by the Numerical Electromagnetic Code (NEC) [30]. With ground reflections, the main-beam peak gain is about 26 dBi at an elevation of about 8° with 8°-vertical and horizontal half-power beamwidths. The application of non-zero phasing to each branch provides off-GCP beam steering realizes the hot-spot adaptive array.

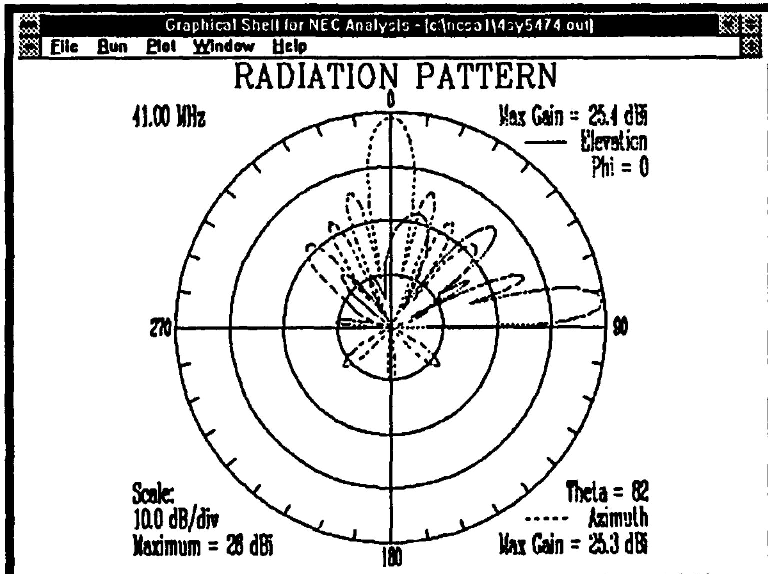

Fig. 6 High-ERP Antenna Array Pattern (0° Shift)

The reference-link transmit system uses the upgraded MCC-6560 to match the terminal employed by the high-ERP link. The 1-kW output of the 6560 is used to drive a pair of stacked horizontally-polarized 7-element Yagis positioned with the phase center at a height of 7/4 wavelength above ground ("REFERENCE" in Fig. 5). Thus, the reference antenna system is similar to one of the four stacked-Yagi combinations composing the high-ERP array, with an operating frequency differing by about 2 MHz. Assuming a

4.8-kW output power for the high-ERP HPA and 6-dB greater antenna gain (four versus one stacked-Yagi combination), the high-ERP link transmit system generates about 12-dB higher ERP than the reference link transmit system.

Receive Systems

High-ERP Link. The high-ERP link uses a receive antenna array identical to the transmit array. Four vertically-stacked pairs of horizontally-polarized Yagis, each positioned at 7/4 wavelength above ground, constitute the receive antenna system. The received signal from each stacked-Yagi combination is sampled by the measurement and recording system (MRS) before input to the phase shifter as shown in Fig. 7. The phase shifter imparts a phase offset to each of the four received signals before input to the four-to-one combiner that precedes the terminal input. To optimize link performance, these offsets are provided by a PC controller according to an empirically-determined diurnal scheduled. Finally, the combiner output is sampled by the MRS before input to one of the 6560 receivers. The 6560 outputs received messages to a PC which correlates these messages with the MRS data for post-processing. The phase offsets imparted to each receive branch are chosen to complement the offsets of the corresponding transmit system so that the resulting transmit and receive beams form a common volume in the most active link hot spot at each time of day. This concept is illustrated in Fig. 2, in which all beams are steered to the eastern side of the north-south link at 12 noon, the most active hot spot available at that time. Combining the maximum receive array power gain G_r (= 26 dBi) with the transmit array gain G_t (= 26 dBi) and the transmitted power P_t (= 36 dBi) yields an ERP of 88 dBW.

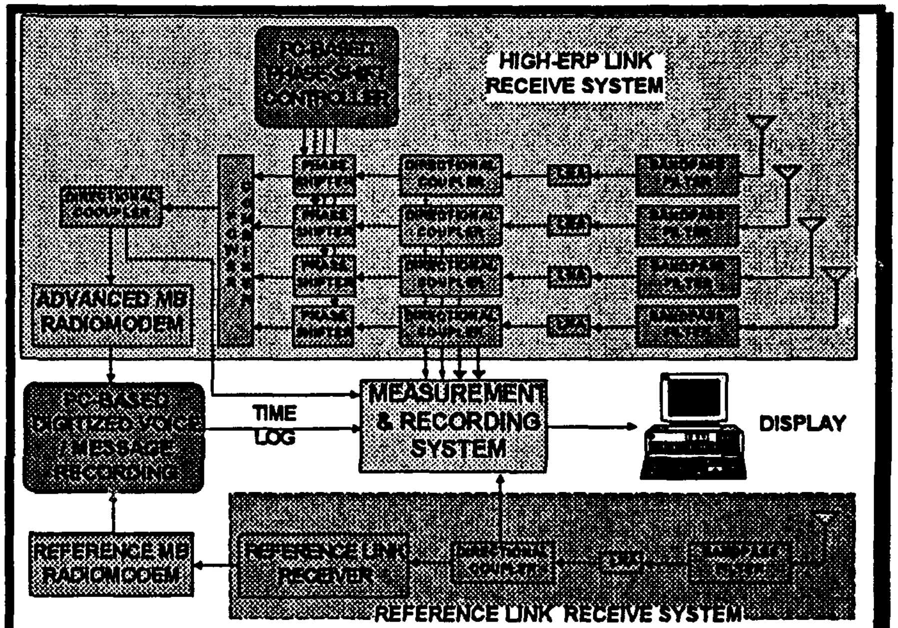

Fig. 7 HEMBLE Receive Systems

Reference Link. The reference link receive system consists of a stacked, horizontally-polarized combination of 7-element Yagis with its phase center positioned 7/4 wavelength above ground. The received signal is sampled by the MRS and then input to one reference-link 6560 receiver. Combining the P_t (= 30 dBi), G_t (= 20 dBi), and G_r (= 20 dBi) values for the reference link yields an ERP of 70 dB, 18 dB below the corresponding value for the high-ERP link. The HEMBLE therefore demonstrates the significant link performance improvement achieved by the combination of high-power and beamforming antenna arrays as compared to a nominal MB system configuration.

The MRS is a significant capability of the HEMBLE, providing near-simultaneous well-calibrated measurements of received signal levels (RSLs) and time-correlated communications performance for both the high-ERP and reference MB links. In this way, a direct comparison of high-ERP and reference link channel characteristics and communications performance can be made. The MRS consists of a 486/33 MHz PC with an optical disk drive providing a 1-Gbyte capacity. Six RSLs are recorded, each of the four RSLs from the high-ERP receive array, the combined high-ERP array RSL, and the reference link RSL. In addition, a digitized voltage calibrated to the detected phase is recorded from each of the four receive branches of the high-ERP array. These phase-value measurements provide a means to determine the dominant azimuthal direction-of-arrival, that is, the bearing angle of the most useful hot spot versus time of day. Post-processing software is employed to distinguish between nonmeteoric RSLs such as skywave, sporadic E, or ducting propagation events and correlate these events with link communications performance. Thus, link performance is provided for all events, exclusively meteoric events, and exclusively non-meteoric events. For meteoric events, underdense trail-scattered signals is separated from overdense or nonspecular trail-scattered signals.

COMPUTER PREDICTIONS

METEORLINK Computer Model

The METEORLINK computer model [31] was employed to determine the optimum antenna designs for the HEMBLE and to predict both the high-ERP and reference link MR and DC values. METEORLINK is a physical arrival model of the MB channel [32] that employs specular trail-scattering geometry requirements to select usable meteor arrivals from a radar-derived sporadic meteor radiant density (SMRD) distribution measured over the celestial sphere. Antenna electric field patterns for all HEMBLE

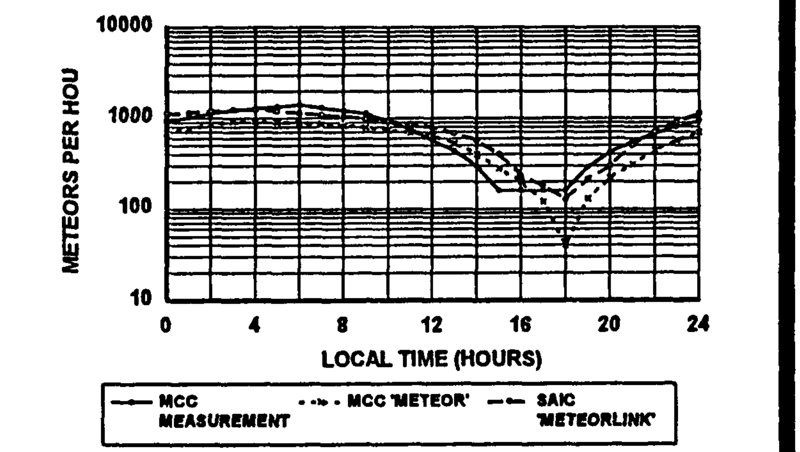

Fig. 8a Northernmost Beam (15°)

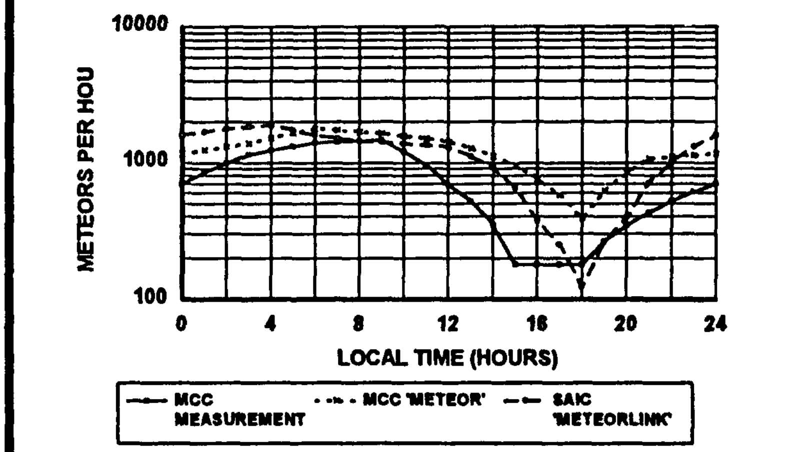

Fig. 8b Northern Beam (7.5°)

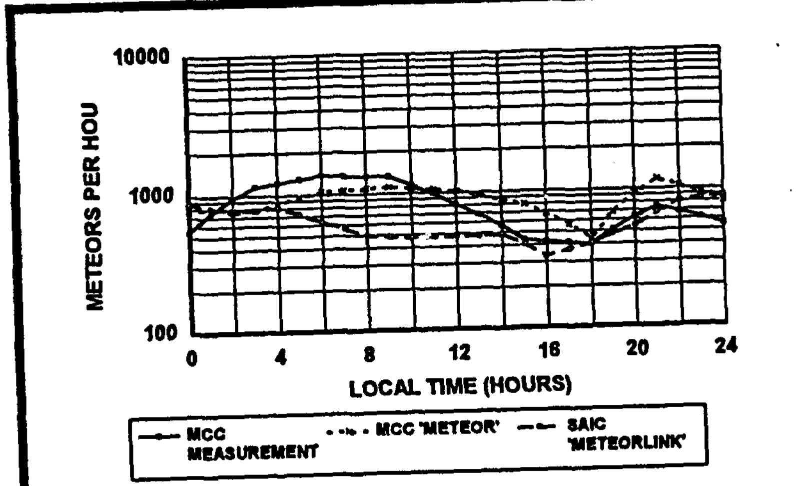

Fig. 8c Southern Beam (-7.5°)

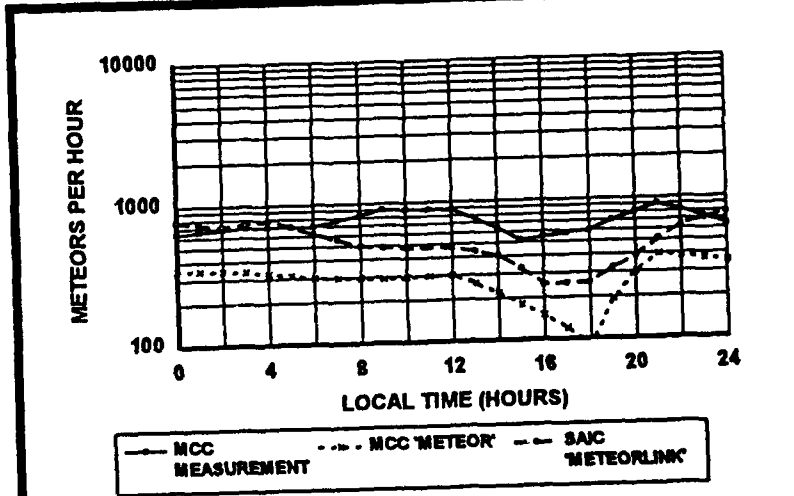

Fig. 8d Southernmost Beam (-15°)

antennas were computed by the Numerical Electromagnetics Code (NEC) version 3I. METEORLINK has been used to predict MR and DC values measured on several MB links, including measurements performed by the Rome Laboratory [33], the Phillips Laboratory [34], MCC [35], the Jodrell Bank Experimental Station [36], and Kazan State University [37]. None of these measurement-prediction comparisons involved ERP values close to the 88 dBW value established for the HEMBLE. Therefore, a measurement-prediction comparison was performed with the high-ERP link operated by MCC in March, 1991 [38].

NEC was used to generate field patterns for the Shelton receive array of four 7-element Yagi antennas and a single transmit Yagi, all at one-wavelength height above ground. Four patterns were generated for the receive array, one for a beam pointed 15° north of the west-to-east bearing to the Bozeman transmit site, one for 7.5° north, 7.5° south, and 15° south. A transmit power of 10 kW was assumed at the Bozeman transmit site and a minimum RSL of -110 dBm was assumed on each of the four receive-beam pointing angles. The measured hourly-average MR values and corresponding MCC METEOR-model predictions were published for each receive beam as well as for the selection-combined output. METEORLINK was used to predict the MR values from each of the four independent receive beams and the results are plotted in Figs. 8a through 8d.

Fig. 8a is a plot of the 15°-north beam MR values versus local time (LT) in Shelton, Washington. The measurements and both the METEORLINK and METEOR predictions show a peak value of about 1000 usable trail-scatter events, or usable meteors per hour, between 4 and 6 LT and minimum values below 200 meteors per hour at about 18 LT. The flattening of the measured MR values between 15 and 18 LT was reported but no explanation was provided by MCC. The measurement-prediction comparison for the 7.5°-north beam MR values is shown in Fig. 8b. In this case, both the METEORLINK and METEOR predictions are more optimistic than the corresponding measurements. Peak MR values occurred between 4 and 8 LT while minimum values were apparent at 18 LT. Fig. 8c shows the results of the measurement-prediction comparison for the 7.5°-south beam. Apparently, the

METEORLINK predictions of the peak MR values from 4 to 14 LT were pessimistic by about a factor of 1/2. This result primarily reflects differences between the assumed SMRD distribution and the actual distribution or discrepancies between the modeled antenna pattern and the actual pattern for the 7.5°-south beam. In this case, the METEORLINK-predicted values were in best agreement with the MCC measurements between 14 and 22 LT. Finally, Fig. 8d plots the measurement-prediction comparison for the southernmost (15° south) beam. Both the METEORLINK and METEOR predictions underestimate the peak MR value and fail to predict the approximate time of occurrence. Minimum predicted MR values are about 1/2 and 1/5 of the corresponding measured minimum values from the METEORLINK and METEOR models, respectively. These results provide some confidence that METEORLINK predictions of expected HEMBLE performance are founded on a comparison with actual high-ERP link performance measurements.

HEMBLE Performance Predictions

The METEORLINK computer model was used to predict performance of the 750-mile high-ERP and reference links between Verona, NY and Charleston, SC for March and July, corresponding to minimum and maximum usable MR values, respectively. NEC antenna patterns were generated for the 56-element transmit and receive (Yagi) arrays and a 4.8-kW output power was assumed at the transmit array. Patterns were created for each array corresponding to main-beam pointing angles of 0°, ±5°, and ±10 ° from the GCP between HEMBLE sites. METEORLINK was used to predict the MR and DC values for the 0°, ±5°, and ±10° array beams using P_r values estimated for burst rates of 2, 4, 8, 16, 32, 64, and 128 kbps provided by the MCC-6560. These burst rates are available within the appropriate receiver bandwidths of 15, 30, 60, and 120 kHz assuming PSK modulation for 2-64 kbps

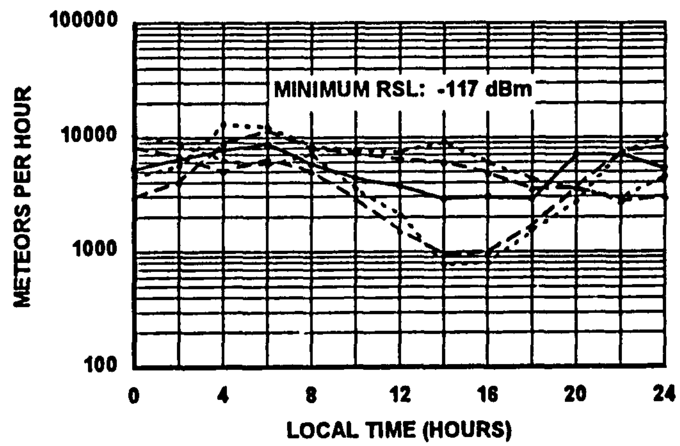

Fig. 9a. MR Values: 2 kbps Burst Rate in March

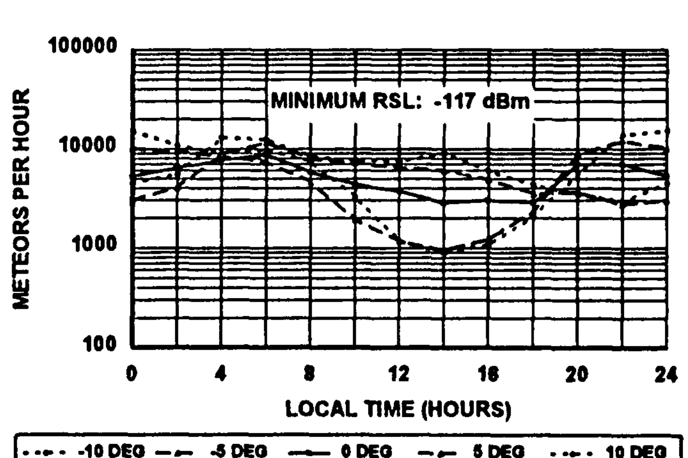

Fig. 9b. MR Values: 2 kbps Burst Rate in July

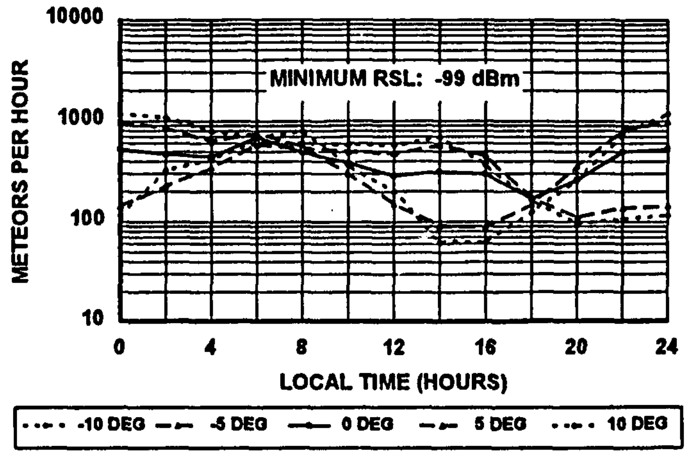

Fig. 9c. MR Values: 128 kbps Burst Rate in March

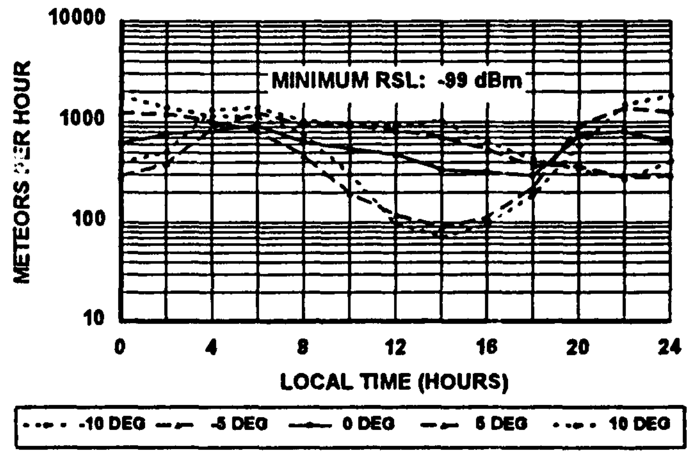

Fig. 9d. MR Values: 128 kbps Burst Rate in July

and QPSK for 128 kbps. A Galactic noise F_a value of 14 dB (see Fig. 4) and a receiver noise figure of 5 dB were also assumed. Figs. 9a-d plot the link MR values versus local time (LT) for the 2 and 128 kbps burst rates and the 0°, ±5°, and ±10° off-GCP pointing angles in March and July, respectively. Note the significant difference in MR values associated with the different P_r values required for the minimum and maximum burst rates. Apparently, the optimum azimuthal pointing angles vary with time-of-day. The 10°-beam pointing angle yields the greatest increase in MR value relative to the GCP-pointing (0°) results between 10 and 18 LT. These results provide preliminary values with which to schedule amplifier and receive-array phase shifts to track the diurnal variation in the location of the dominant meteoric hot spot.

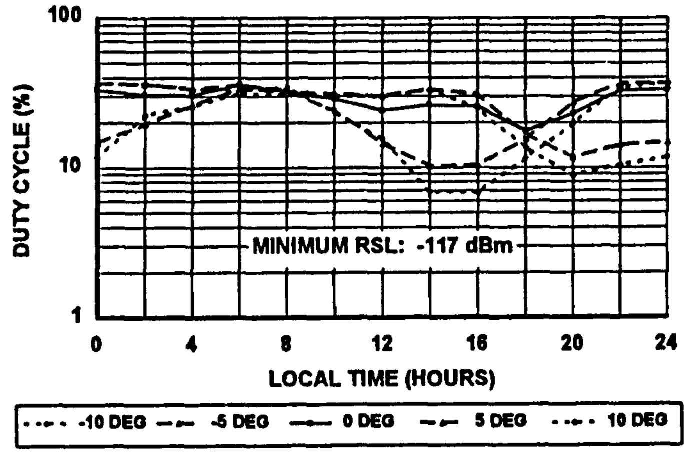

Fig. 10a DC Values: 2 kbps Burst Rate in March

The DC values corresponding to the MR values plotted in Figs. 9a-d are plotted in Figs. 10a-d for March and July, respectively. The plot shows DC values that have been scaled to account for the occurrence of simultaneous usable trail-scattered signals produced by more than one meteor. Thus, if $T_f(b_r)$% is the DC value predicted at a b_r kbps burst rate, then the DC value due to exactly one meteor trail is given by $T_1(b_r) = T_f(b_r) \exp(-T_f(b_r)/100)$ %, where $T_1(b_r)$ is the desired single-trail DC value above the corresponding RSL threshold. This scaling is necessary because METEORLINK sums DC contributions throughout the link common volume without

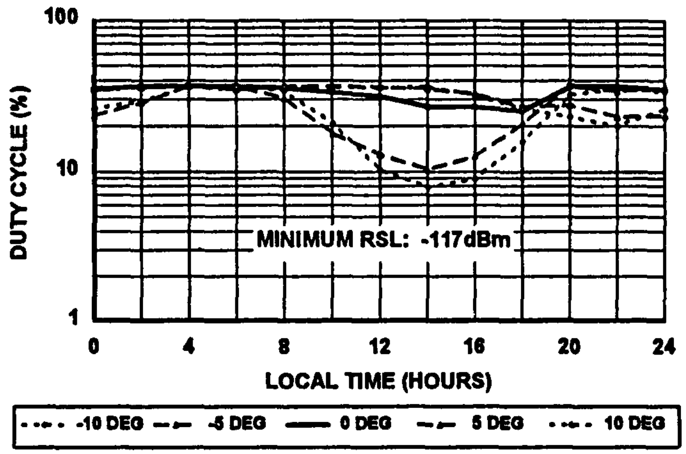

Fig. 10b DC Values: 2 kbps Burst Rate in July

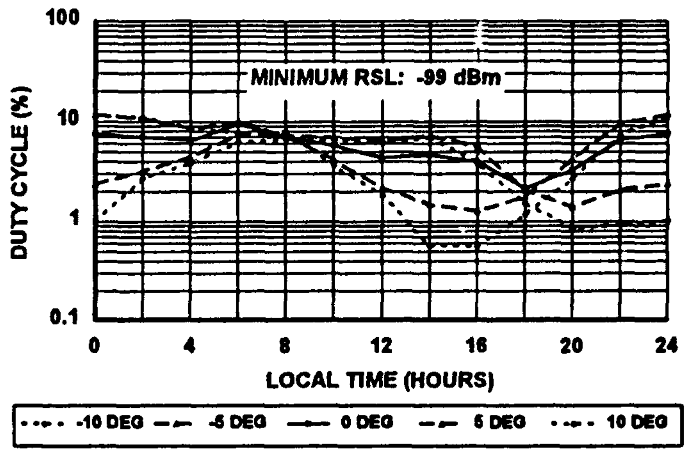

Fig. 10c DC Values: 128 kbps Burst Rate in March

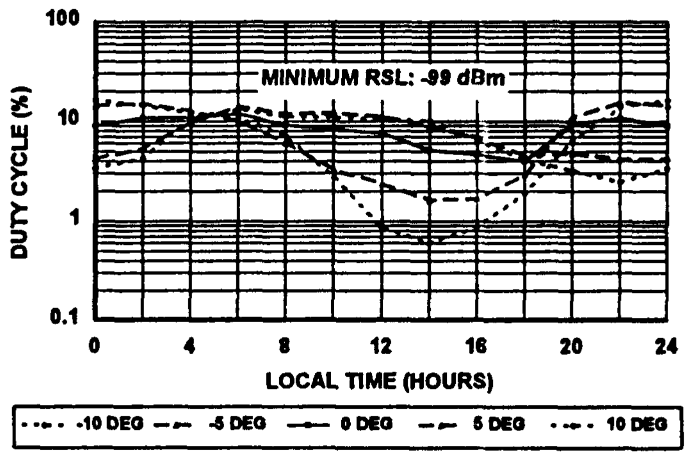

Fig. 10d DC Values: 128 kbps Burst Rate in July

regard to the simultaneity of independent trail-scattered signals. As shown in Figs. 10, this effect is significant at 2 kbps where link MR values are so high that the corresponding predicted DC values could exceed 100%. At 128 kbps, the MR values are significantly smaller and the probability of simultaneous usable trail-scattered signals is negligible.

Figs. 12a and b plot the no-protocol throughput for the HEMBLE high-ERP link versus time of day and main-beam pointing angle in March and July, respectively. The "no-protocol" descriptor implies that the throughputs shown in Figs. 11 and 12 include all bit synchronization, link, and network protocol overhead as well as message or data bits. In addition, the "VARIABLE" throughput values plotted in these figures were determined for an idealized variable burst-rate modem. Measured results due to practical implementations of variable burst rate, such as employed by the MCC-6560, are expected to be below these predicted values. The "MAX" curve represents the maximum average throughput expected during any hour of the day. It corresponds to the performance expected from the hot-spot adaptive antenna array, which focuses its beam at the optimum bearing angle for each hour of the day. Compare these results to the 2-kbps minimum hourly-

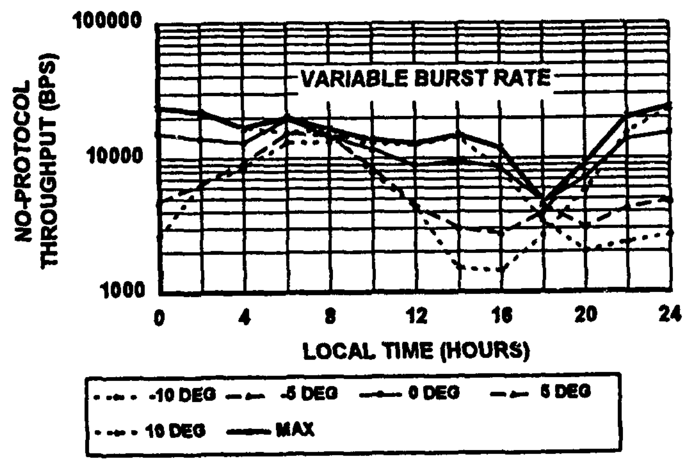

Fig. 11a Average No-Protocol Throughput in March

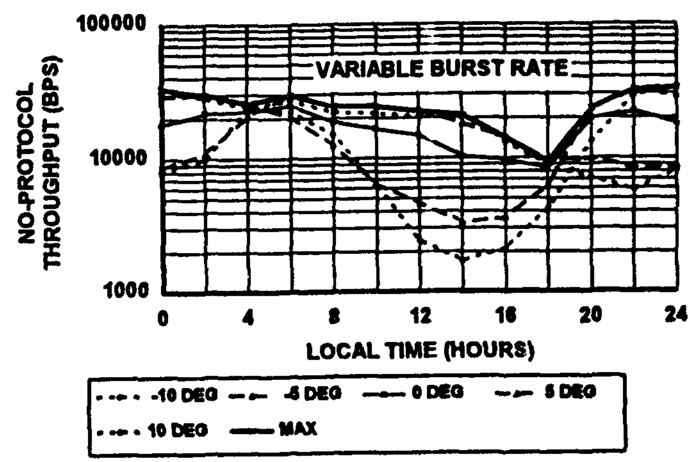

Fig. 11b Average No-Protocol Throughput in July

averaged message-bit throughput measured on the MCC high-ERP link in April, 1991 [39]. The HEMBLE high-ERP link should achieve the 2-kbps minimum message-bit throughput if the scaling factor from the METEORLINK-predicted no-protocol values to the corresponding message-bit values is no more than a factor of 1/2.

The optimum pointing angles for each bihourly interval taken from Figs. 11a and 11b provide an initial set of values for use in the array phase controllers shown in Figs. 4 and 7. The high-ERP link no-protocol throughput values are compared with corresponding reference link throughput values in Figs. 12a and b for March and July, respectively. Reference link results are shown both for an 8-kbps fixed burst rate and a 2-128 kbps variable burst rate. The reference link results were computed assuming a single pair of stacked 7-element Yagis and both fixed 8 kbps and 2-128 kbps burst rates. Clearly, the high-ERP link significantly outperforms the 8-kbps reference link, with a no-protocol throughput-improvement factor showing a daily-average value of about ten. The use of variable burst rate versus 8-kbps fixed rate on the reference link reduces this improvement to about a factor of three. These ratios provide predicted values for the ratios derived from HEMBLE measurements.

SUMMARY & PLANS

This paper describes the experimental portion of ARPA's advanced meteor burst demonstration program. Predicted results show that a high-ERP MB link employing a high-gain, steerable array can provide a factor of ten increase in the diurnal average no-protocol throughput. This result occurs despite the reduction in effective DC values at the lower burst rates due to overlapping trail-scattered signals. The steerable array permits tracking of the meteoric hot spots, which migrate throughout the day due to diurnal

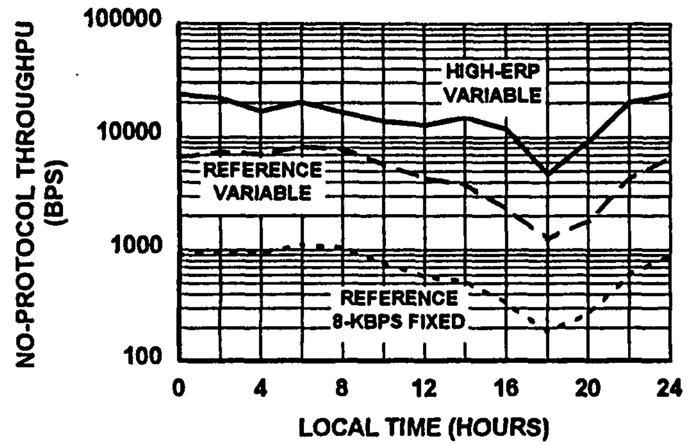

Fig. 12a. No-Protocol Throughput Comparison in March

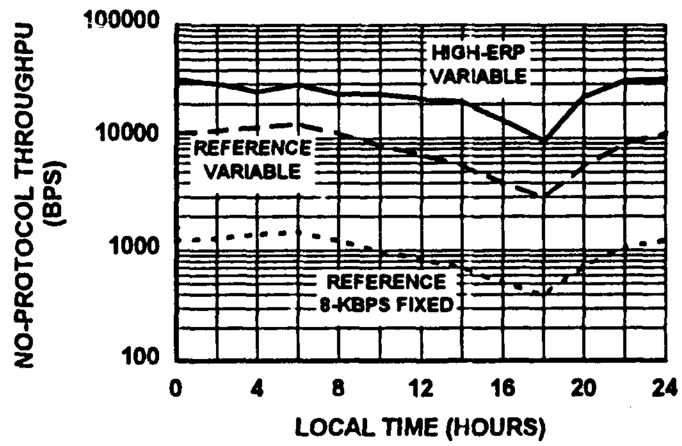

Fig. 12b. High-ERP & Reference Throughput in July

variation in the arrival direction of meteors producing usable trail-scattered signals. The variable burst rate makes maximum use of the wide range of available SNR values typical of a well-designed MBC link.

The high-ERP link provides an important test bed for reevaluating the ionoscatter link characteristics first explored more than 40 years ago. The modern data acquisition and processing technology employed in the HEMBLE, however, permit a much more extensive empirical study and evaluation of ionoscatter phenomena. Shorter range links are also planned, requiring a wider azimuthal swing of array off-GCP pointing angles to achieve best link performance than for the current 750-mile HEMBLE path. Additional beamforming techniques, such as the multiple simultaneous (Butler-matrix) approach proven by MCC as well as retrodirective trail-adaptive techniques [40], are also planned. Improved MB modems requiring less channel bandwidth, but nevertheless achieving adequate burst rates to make efficient use of the available SNR values, have also been considered. HEMBLE demonstrations are planned to include the transmission of digitized voice and imagery data as well as message text using state-of-the-art data compression techniques to increase information throughput. These demonstrations are intended to heighten Government and commercial awareness of the performance achievable with state-of-the-art MBC technology for the solution of unique communications problems.

ACKNOWLEDGMENTS

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